# Resilient Facade Design: Innovation Amidst Earthquakes

**Automation of the structural analysis of a wooden and aluminium suspended facade under earthquakes and development of a bracket connection using FEM Models.**


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Collaboration
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# Acknowledgements….

## Introduction

### Problem Statement

## Literature Review

### Suspended Facades under earthquakes

- Suspended facades elements, detailing
- How suspended facades are affected by earthquakes.

### Site Selection, Architectural Proposal

- Groningen Netherlands Earthquakes, Wind
- Architectural Proposal
  - Aluminum Curtain wall
  - Wooden Curtain wall

### Finite Element Analysis and Materials

- Facade materials
- Structural Glass
  - Material Properties
  - Why structural Glass?
  - Developed structural Glass elements.

### Suspended facades Structural Analysis

- Free-form diagram
  - Seismic Forces
  - Wind Pressure
  - Combination of forces

## Tools developed, Outputs

### Automation of the structural analysis

- Data Analysis
  - Seismic force according to building height
  - Seismic force with different building frequencies
  - Seismic force with different facade frequen-cies
- Implementation of the Automation process
  - Building creations, in -time data outputs

### Development of a structural Glass Bracket Connection

- Design of a glass bracket connection
  - Composite bracket
    - FEM Analysis
      - Under wind forces
      - Under earthquakes

## Conclusion

### Future Development

## Main Idea…

Magnitude 6.2 earthquake struck central Italy to the southwest of the town of Norcia 2016

Source: timemagazine.com

**Magnitude 7.6 earthquake Ishikawa Prefecture, Japan 2024**
Source: nltoday.news

**Magnitude 6.4 Island of Samos Greece 2020**
Source: cnn.com

**Between 1998 and 2017, earthquakes accounted for over 750,000 fatalities worldwide and affected over 125 million individuals, leading to injuries, displacement, homelessness, and emergency evacuations.**

## Main Idea…

***If a city can be resilient to the natural disasters occurring, then it can prosper both socially, economically with regards to the environmental impacts.***

## Main Research question:

***How can the integration of automation technologies in engineering processes, coupled with finite element analysis, facilitate the development of cost-effective and sustainable brackets to fortify the building's suspended facade against seismic activities?***

## Sub-questions:

How can the structural analysis of a façade become less challenging for architects, civil engineers, façade advisors?

How brackets withstand extreme conditions such as earthquakes?

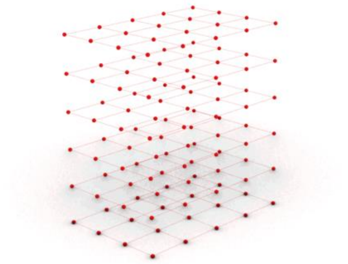
Can we use structural glass as a bracket system and withstand seismic and wind forces?

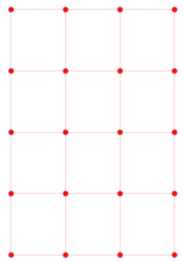
How can a computational tool calculate the forces a suspended façade has to withstand from earthquakes and wind pressure?

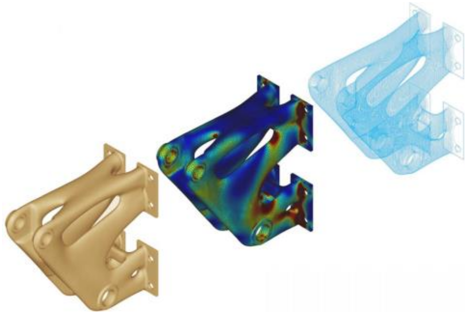
How can the efficiency of researching new materials for a façade system in extreme conditions be improved?

# Design Vision

**Design and develop a tool that will calculate the forces that a bracket must withstand in seismic events, afterwards use Finite Element Method modelling to propose a composite bracket made from glass and steel.**



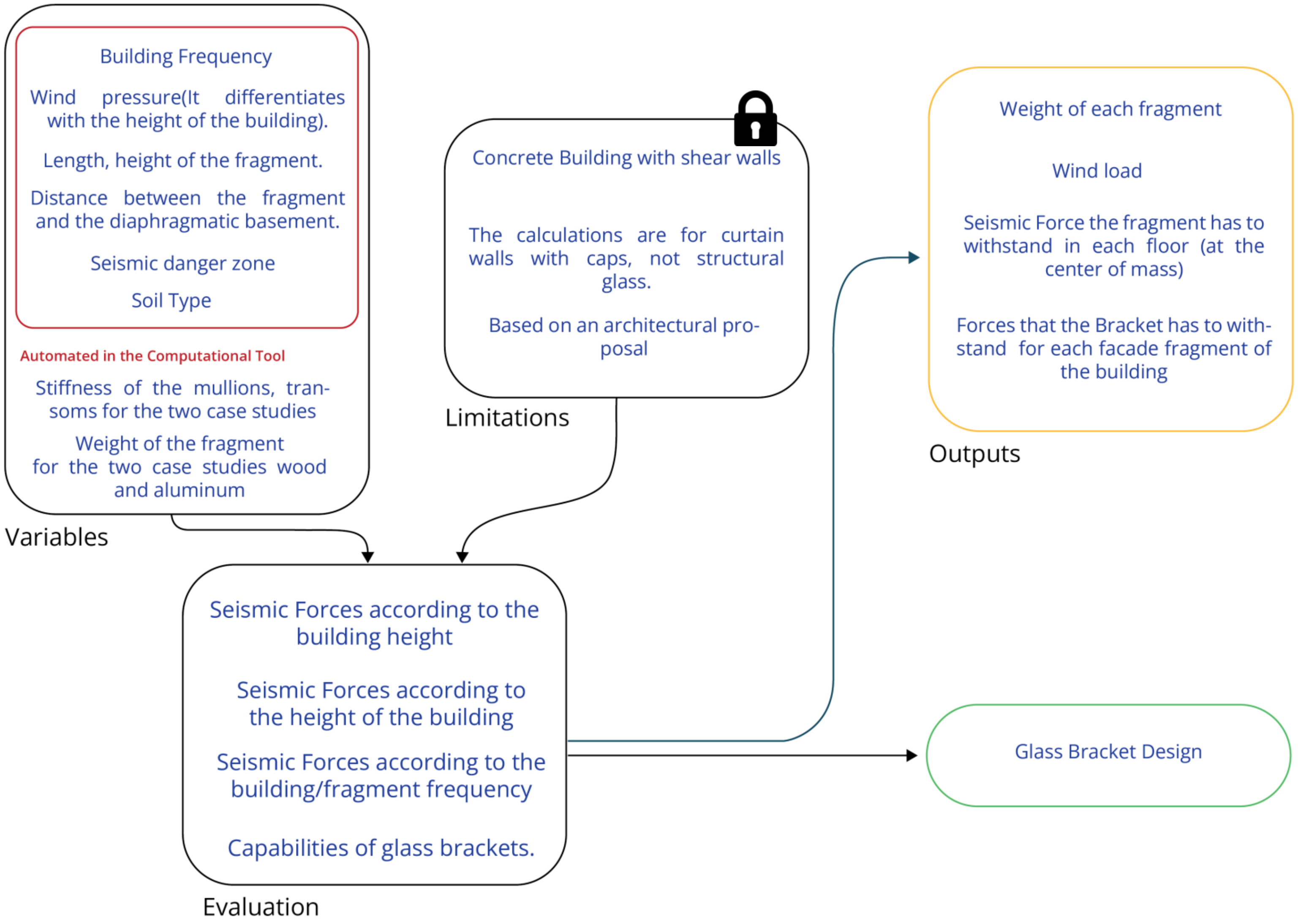




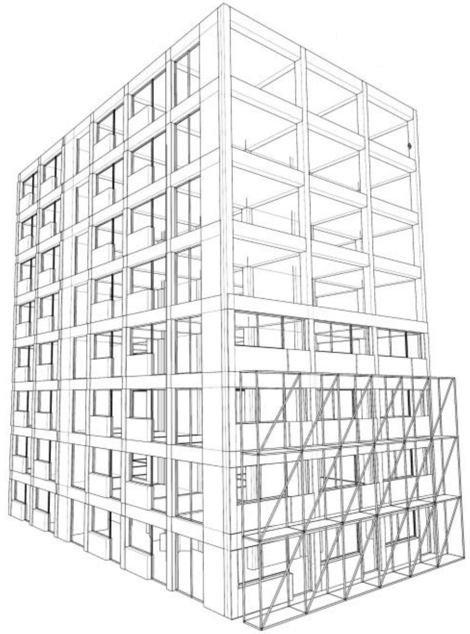
# Design Vision

Interior of an office building designed by the computational tool

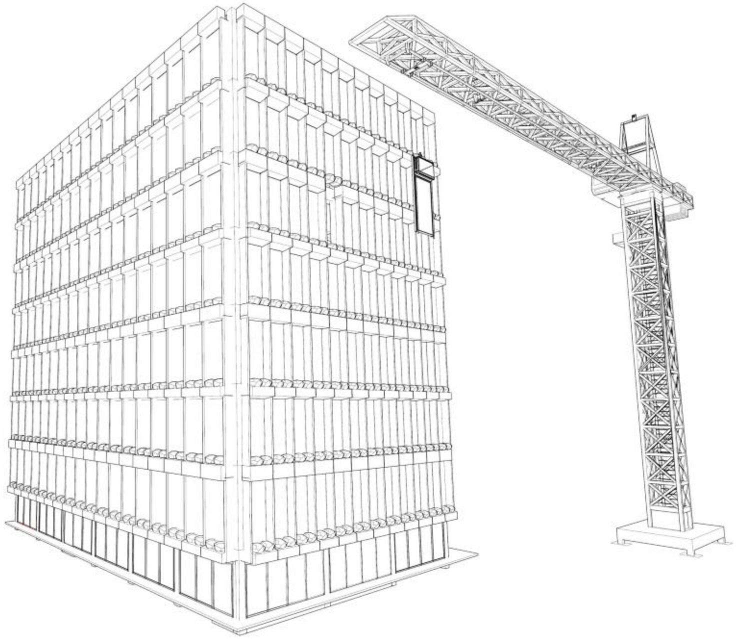
# Variables, Limitations



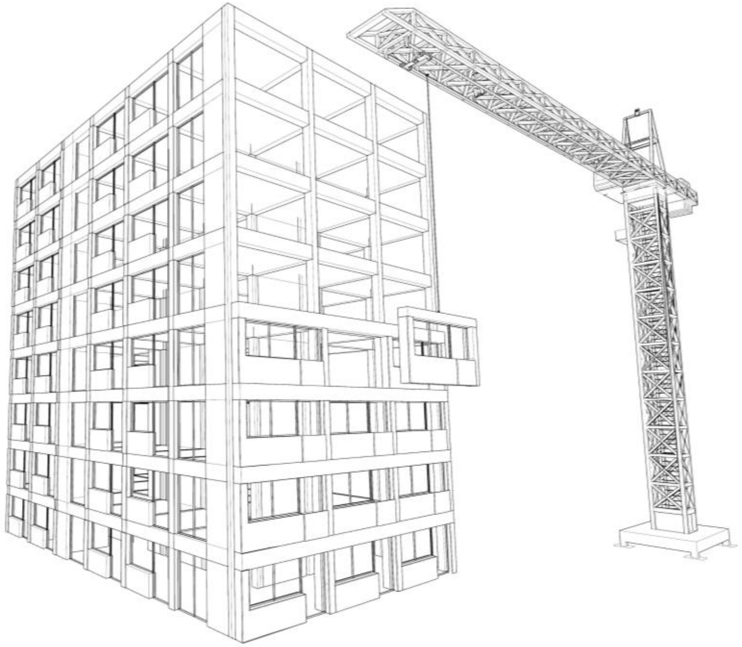
# Facade typologies



Load Bearing facades

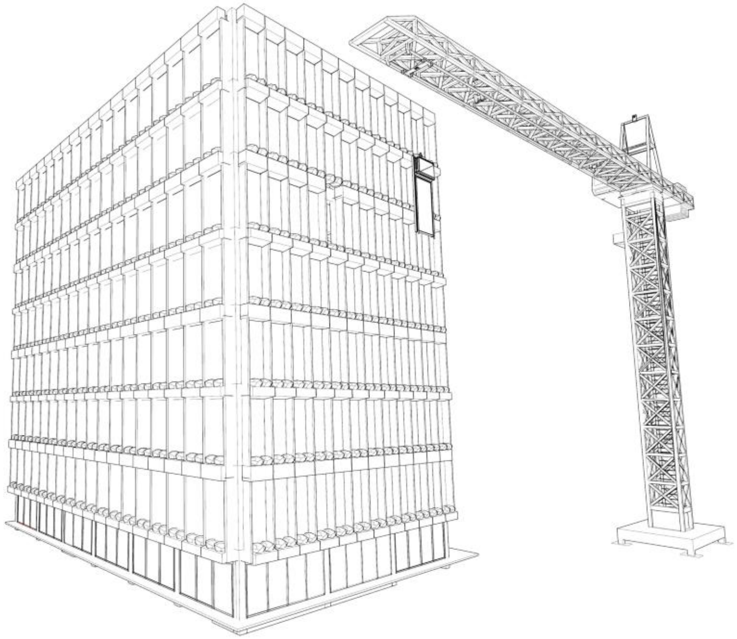


Suspended facades



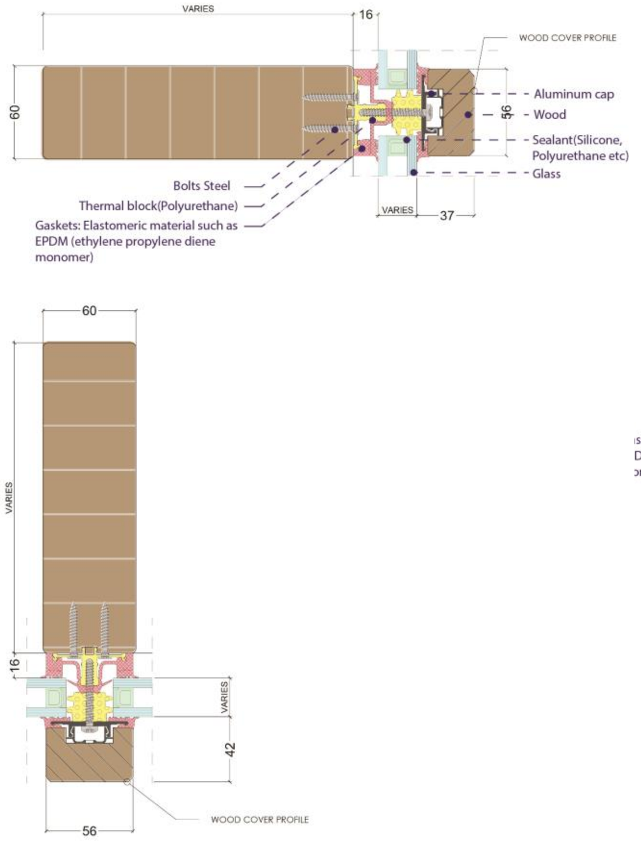
Plinth facades

## Suspended facades, advantages

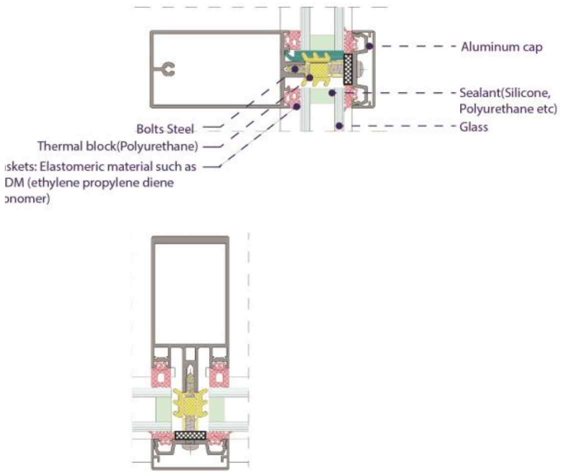


- Freedom of design
- Easily replaceable (compared to the utilised curtain wall system)
- Maximum view and natural light
- Faster Installation
- Lightweight
- Modular and developed in a factory(limited errors resulting in better thermal insulation and watertightness)

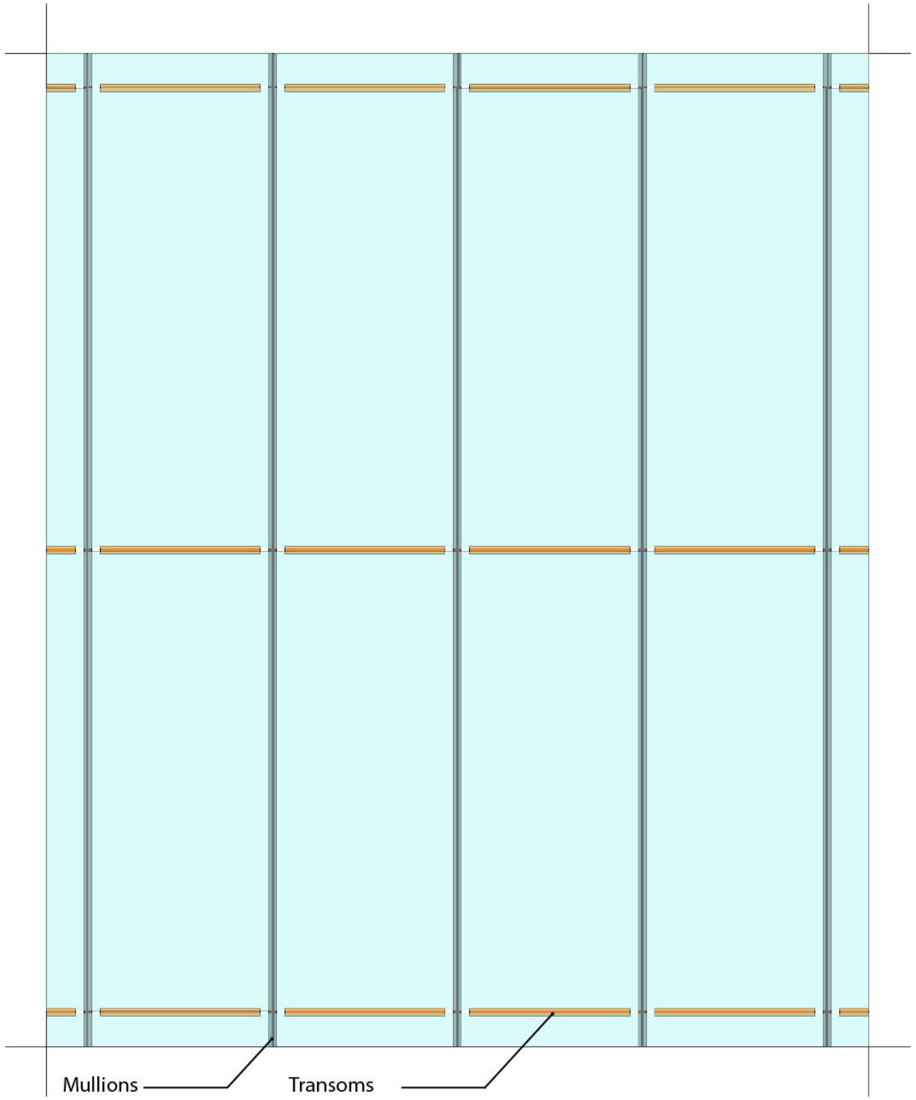
# Timber, aluminum Frames Detailing zones




Source: Unicel Architectural, Model: Therm +56




Source: Schuco, Model: FWS 50

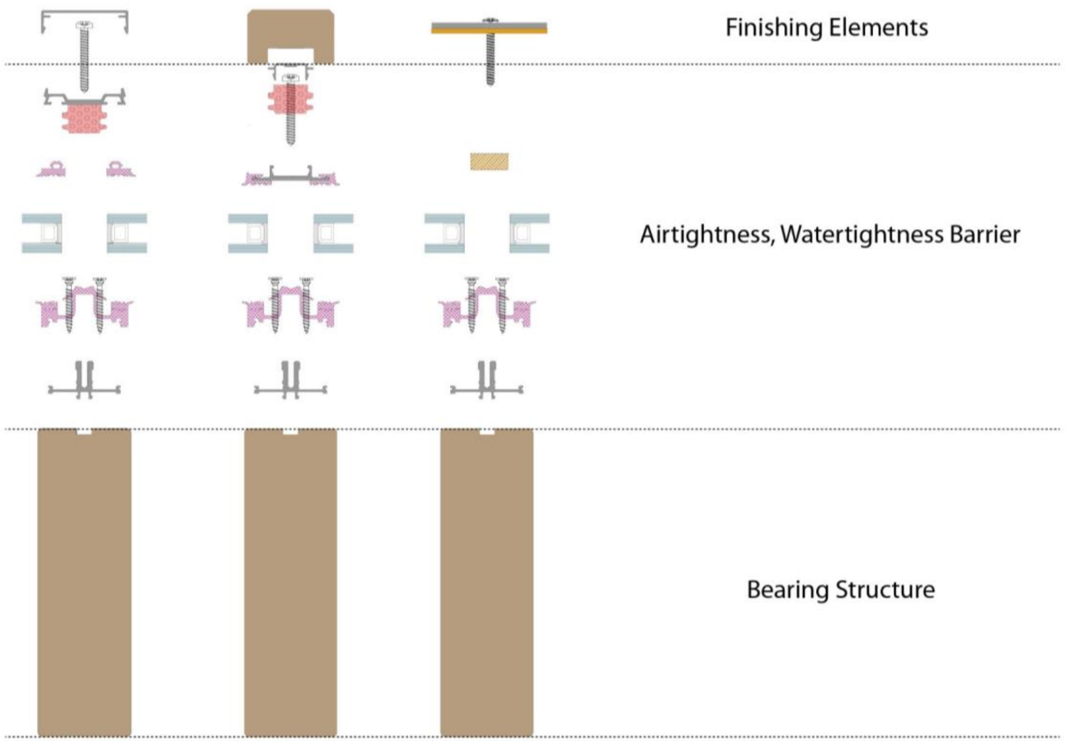



Introduction

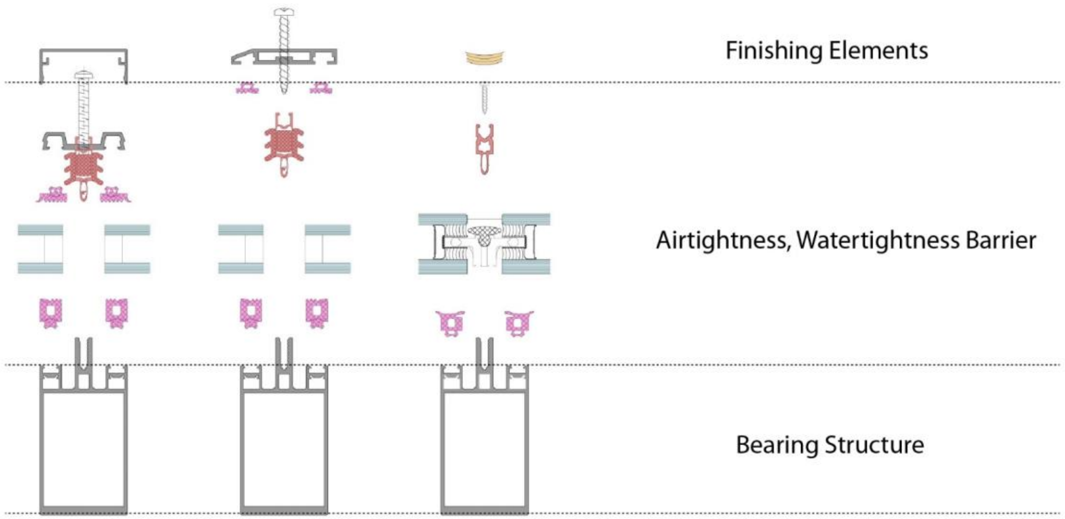
Literature Review

# Timber, aluminum Frames Detailing zones

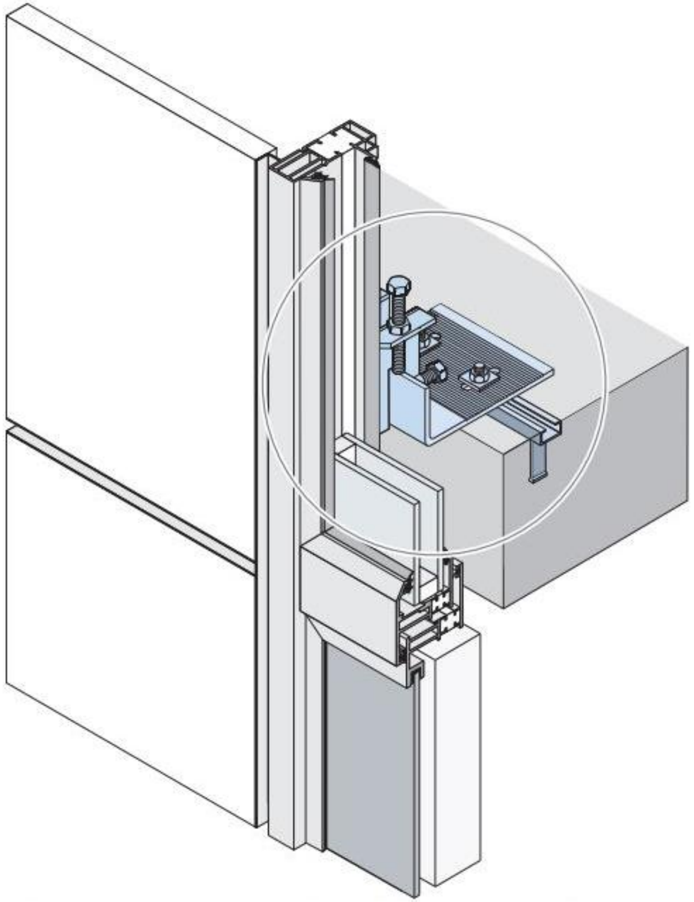
Timber Composite Frames



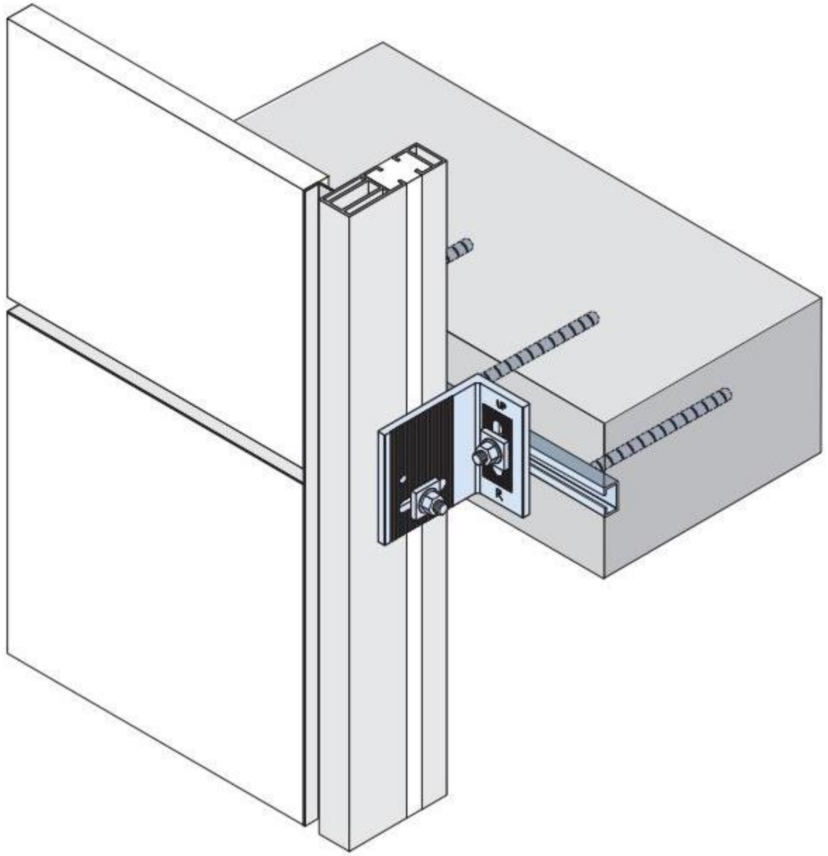

Aluminum Frames



# Bracket systems



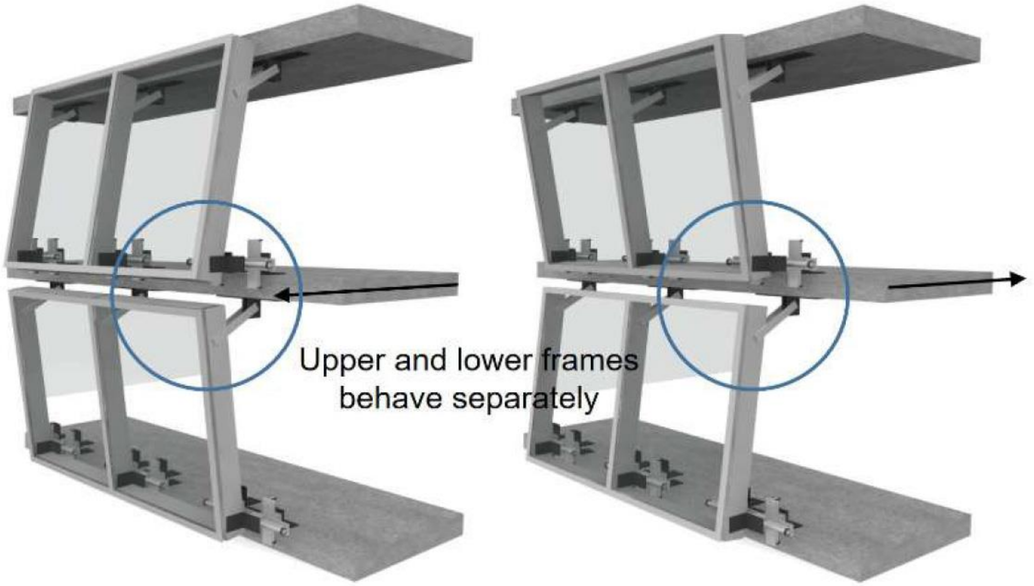
HALFEN Anchor Channels — top of slab application



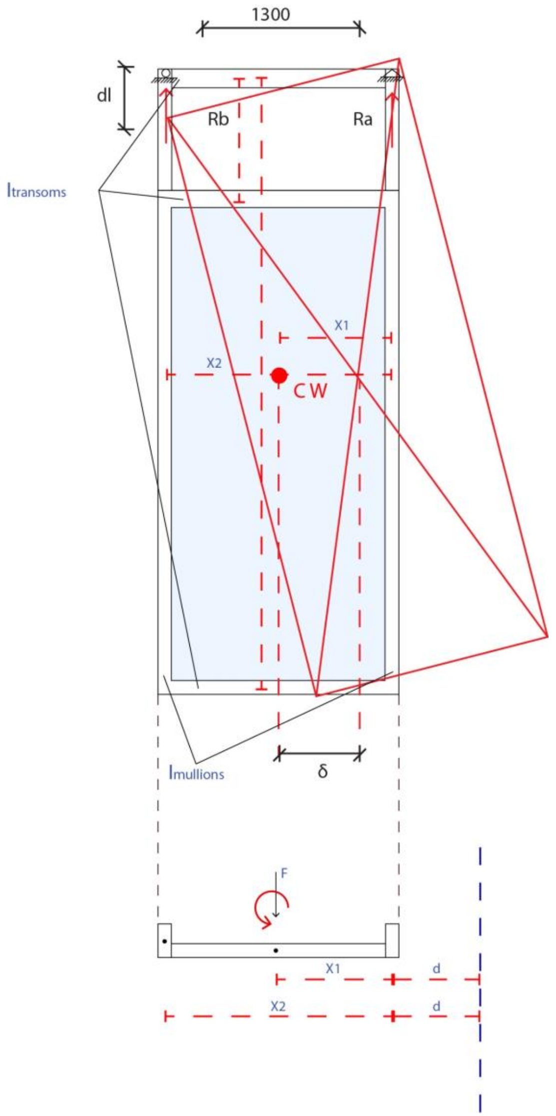
HALFEN Anchor Channels — edge of slab application

Source: Halfen

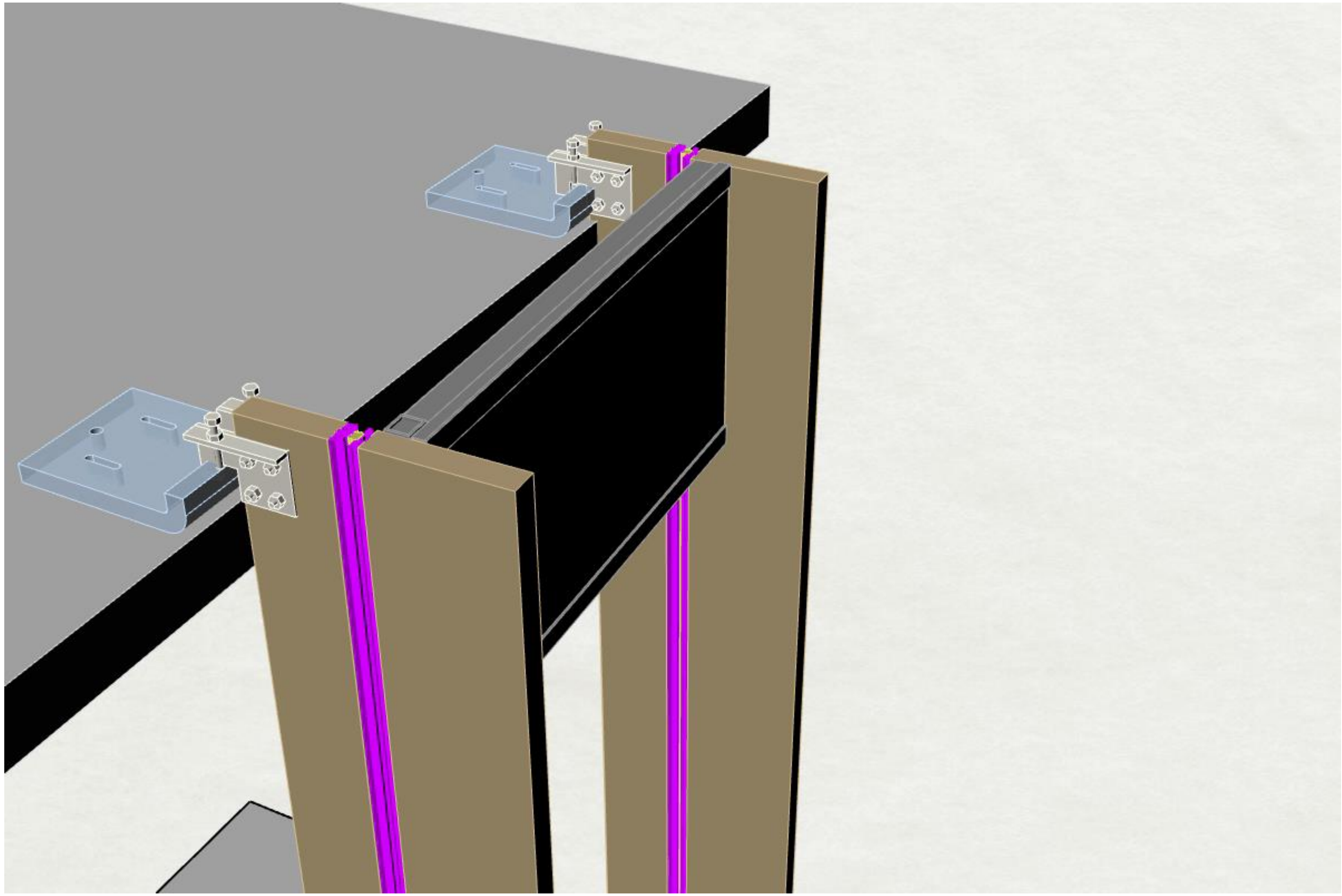
# Suspended facades Under Seismic Events



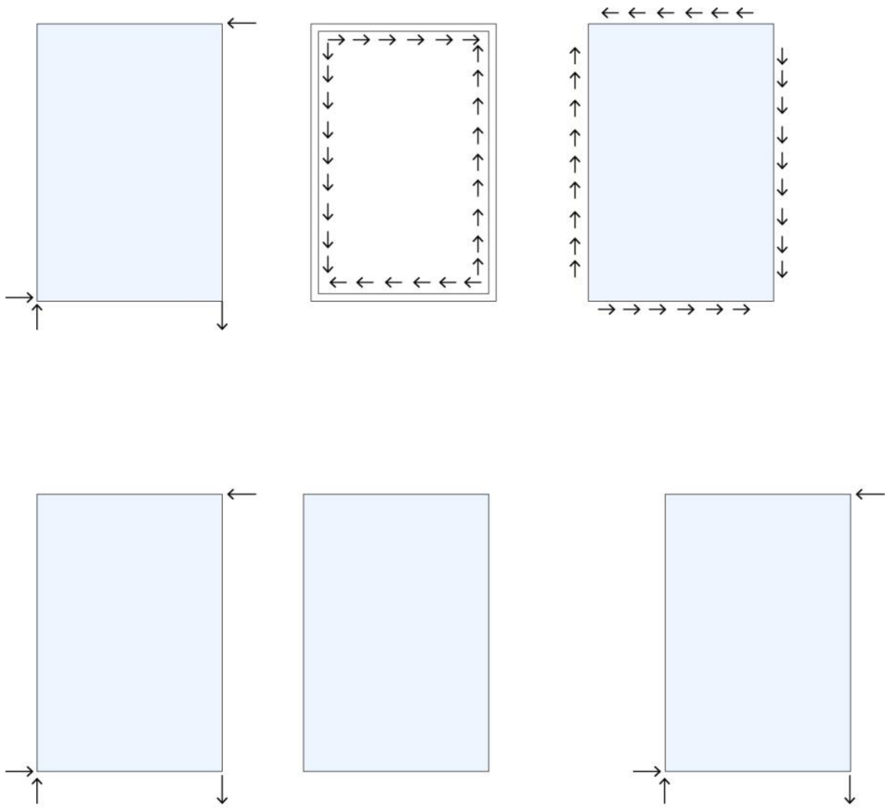

Source:**Seismic and Energy Performance Evaluation of Large-Scale Curtain Walls Subjected to Displacement Control Fasteners. Heonseok LeeMyunghwan Oh**

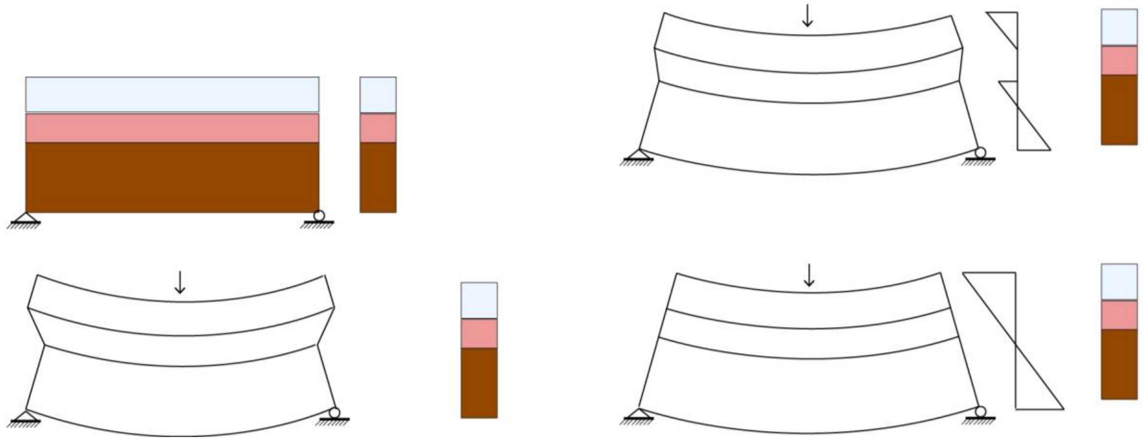


## Suspended facades Under Seismic Events



# Forces distribution in a façade fragment



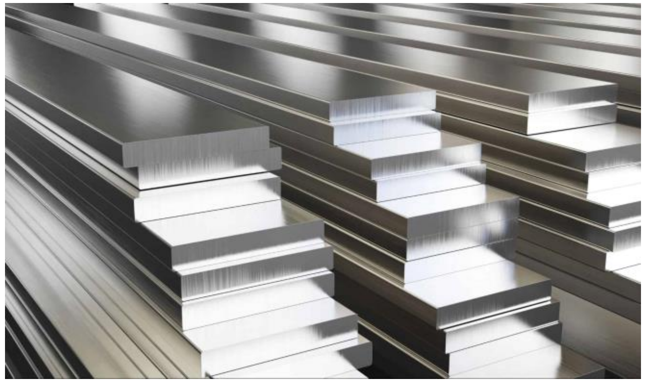


# Suspended Façade Materials

## Timber


Source:https://glulamte.co.uk/

## Aluminum



Source: industrialmetalservice.com

## Structural Glass

Source: keraglass.info

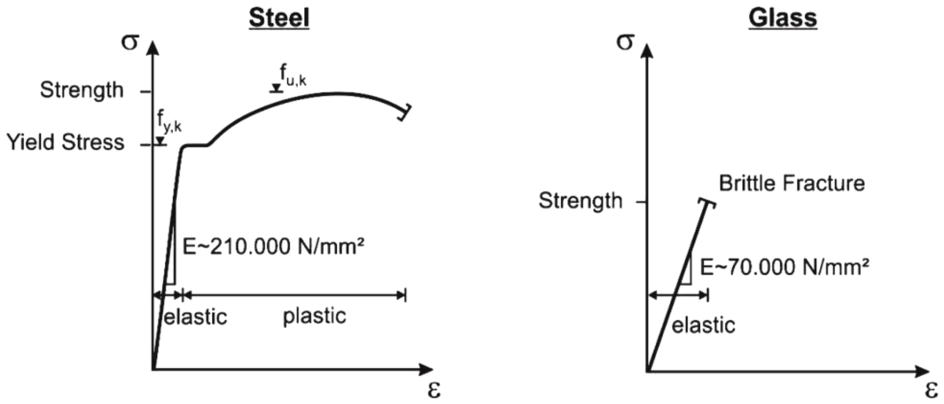
## Rubber Materials

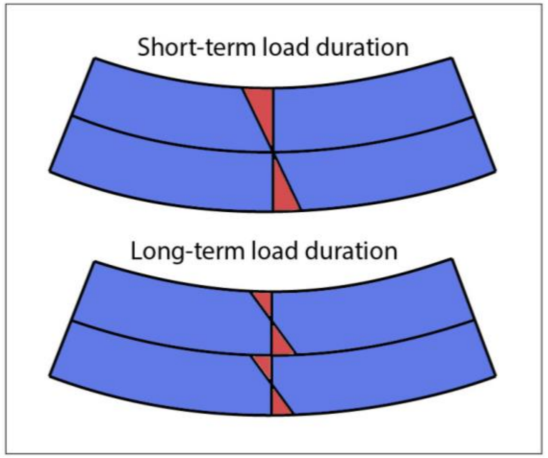
Source:https://moritequsa.com/

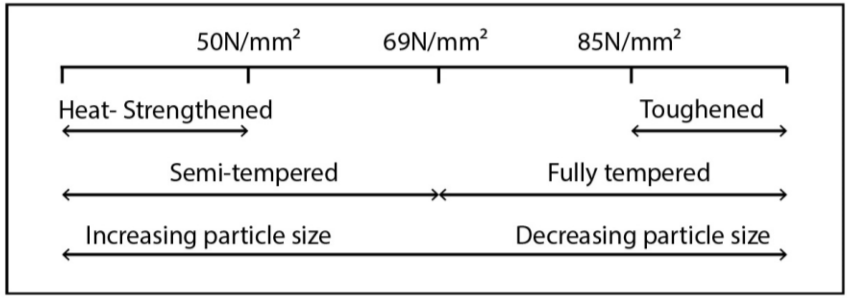
## Polyurethane

Source:https://www.gbfoamdirect.co.uk/

# Finite Element Method Models Inputs




Source: Structural use of glass in buildings. C. O'Regan

## Why structural glass?

Glass is 100% recyclable and can be recycled indefinitely without losing quality or purity.

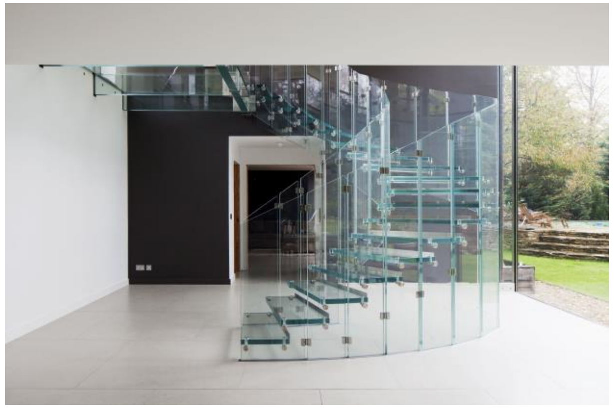
It offers a unique aesthetic quality; it allows transparency and can be in a variety of colours.

Structural glass is highly durable and resistant to weathering, which means it has a long lifespan and requires minimal maintenance.

Structural glass has a lower thermal conductivity comparing to steel. (structural glass 1 W/m·K, steel 45 W/m·K

Source: https://www.archdaily.com/

# Materials Research, Structural Glass



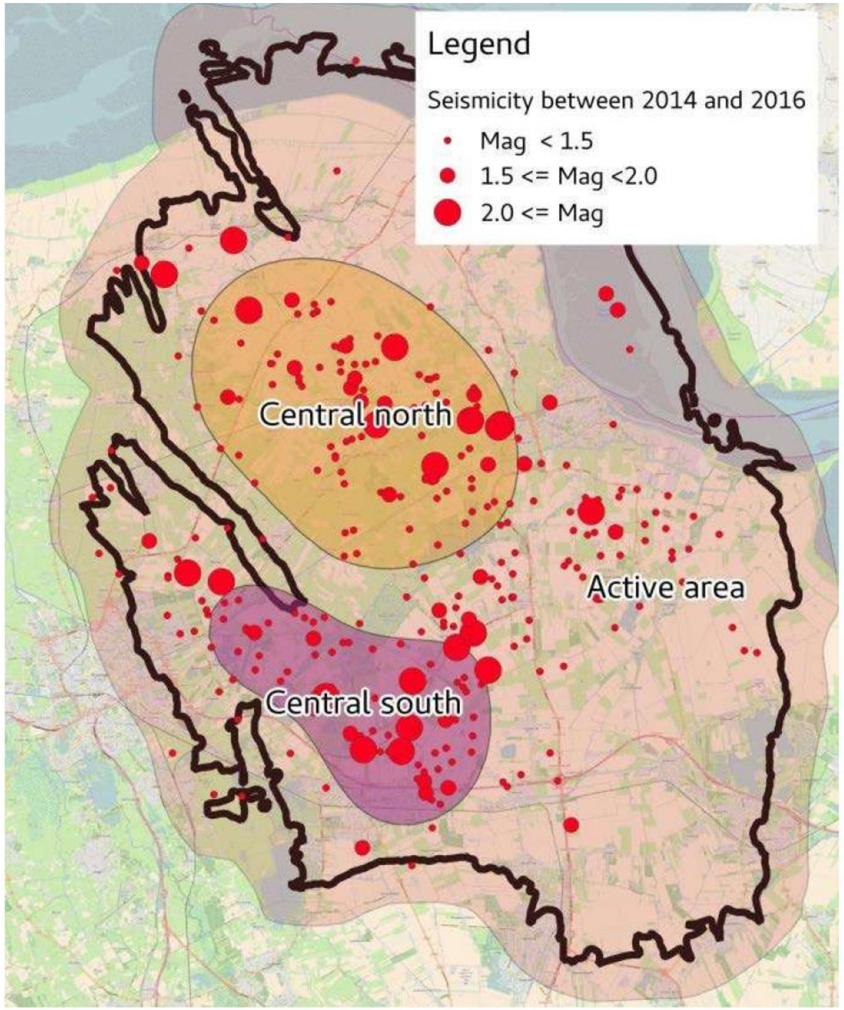
www.stairs-siller.com

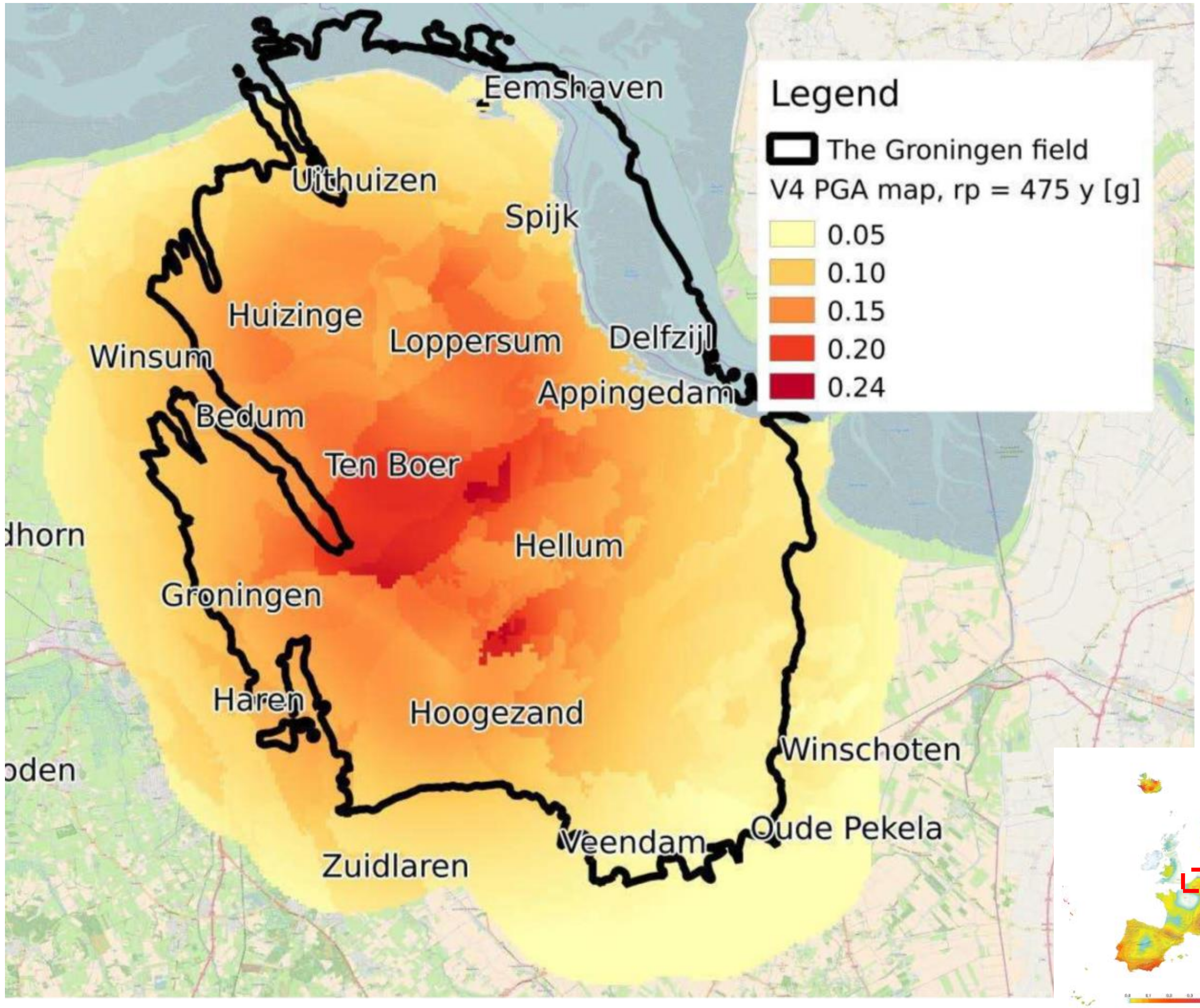
www.apple.com.cn/retail/kunming/

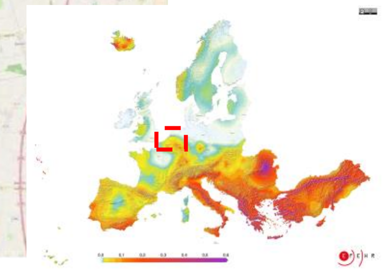
www.archello.com/product/load-bearing-glass-beam

www.architecturaldigest.com

# Site selection, Groningen Netherlands



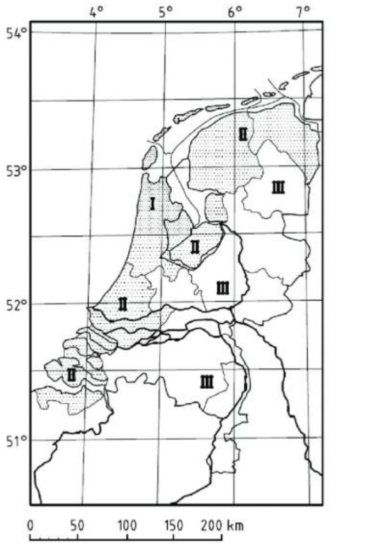



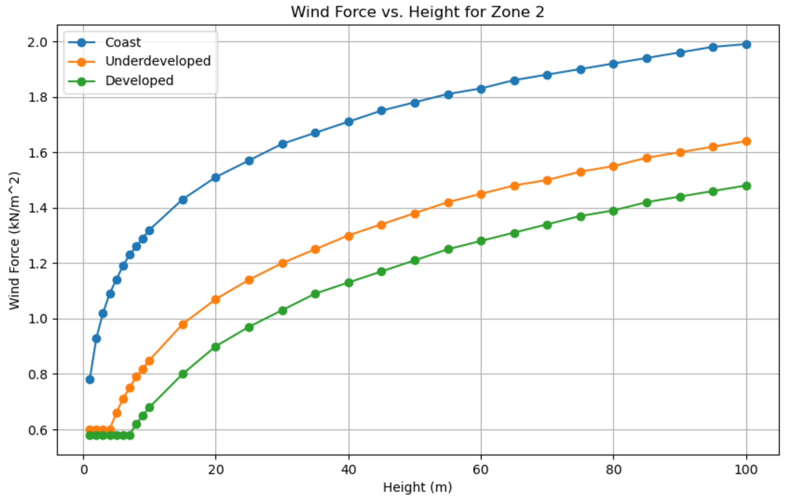
•Source: Development of seismicity and probabilistic hazard assessment for the Groningen gas field, Geologie en Mijnbouw

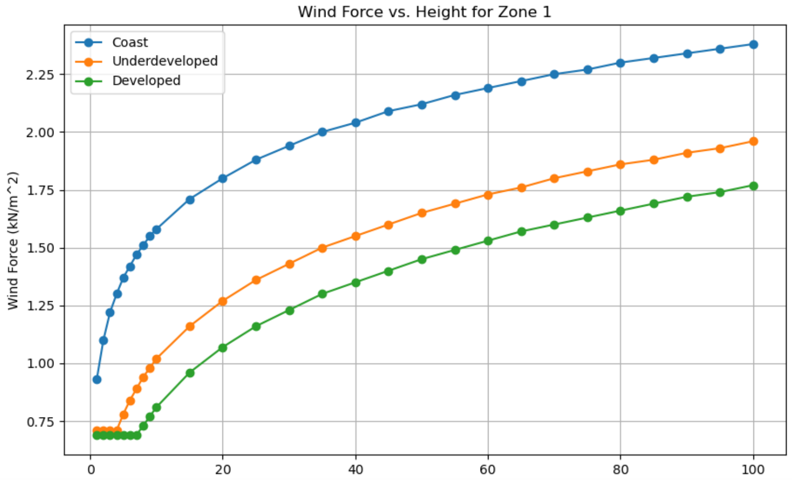
Source: http://www.efehr.org/

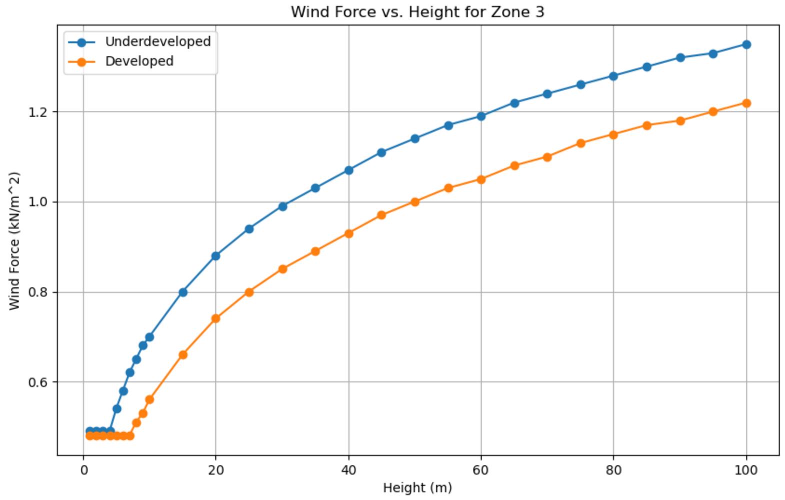
# Site selection, Groningen Netherlands




Source: Classification of the Netherlands in wind areas (NEN, 2011)



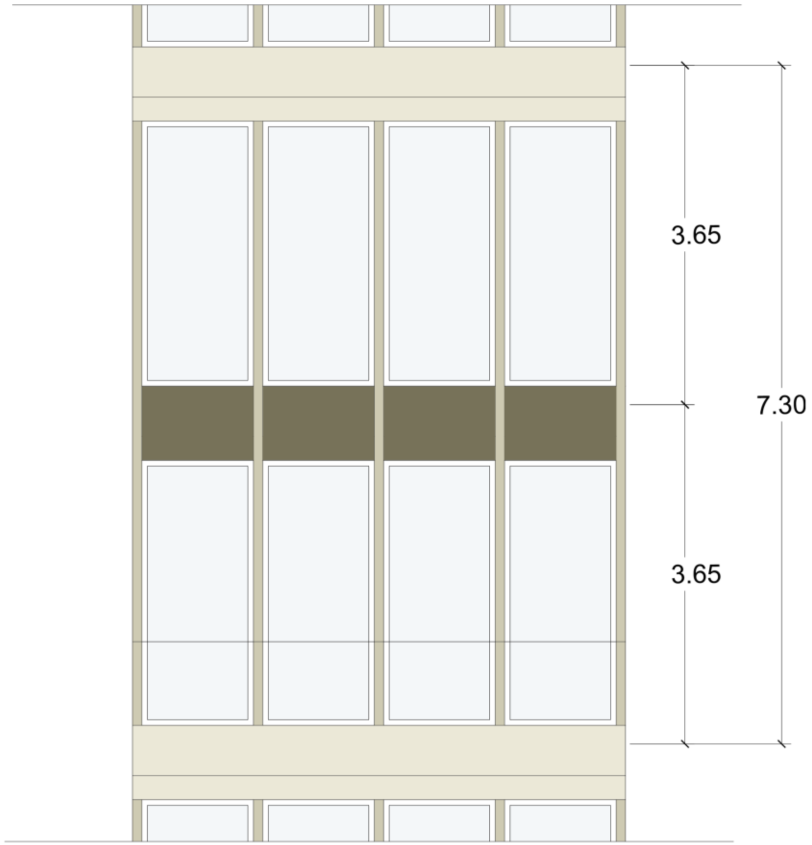



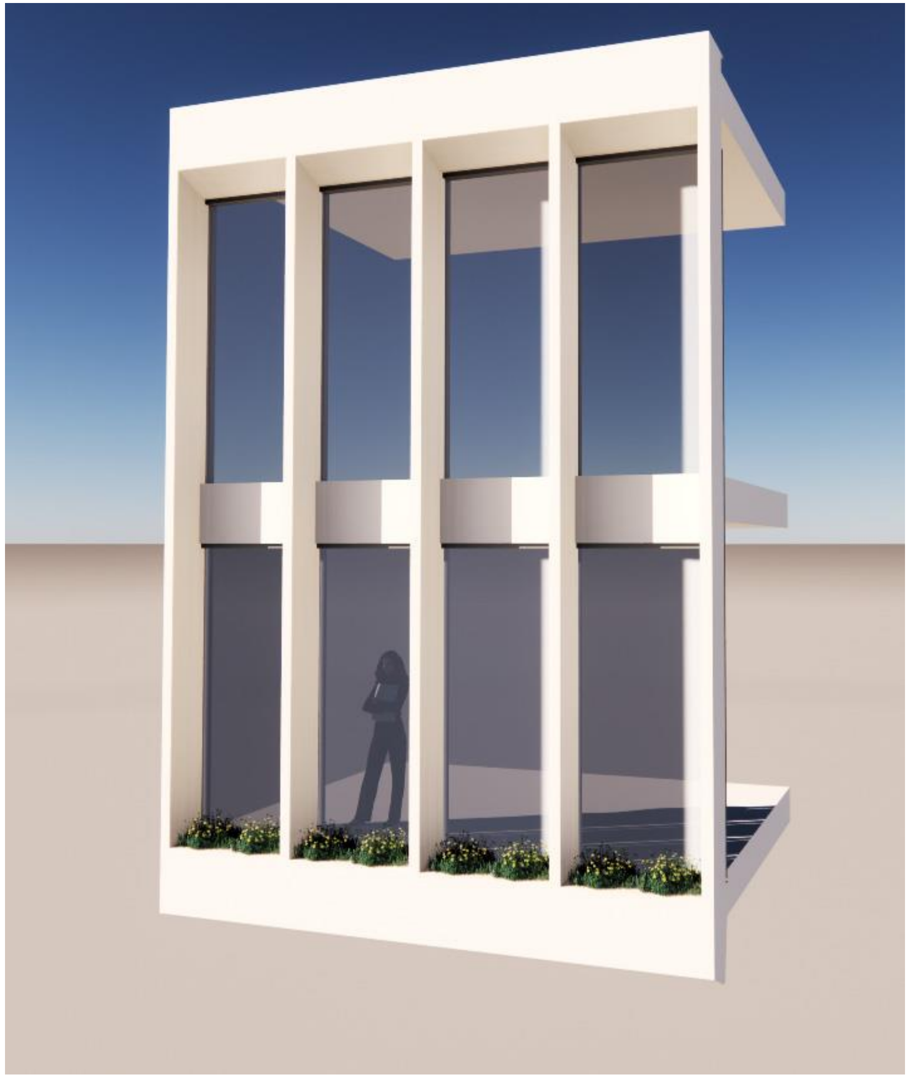

Classification of the Netherlands in wind areas (NEN, 2011)

# Architectural Proposal, Aluminum

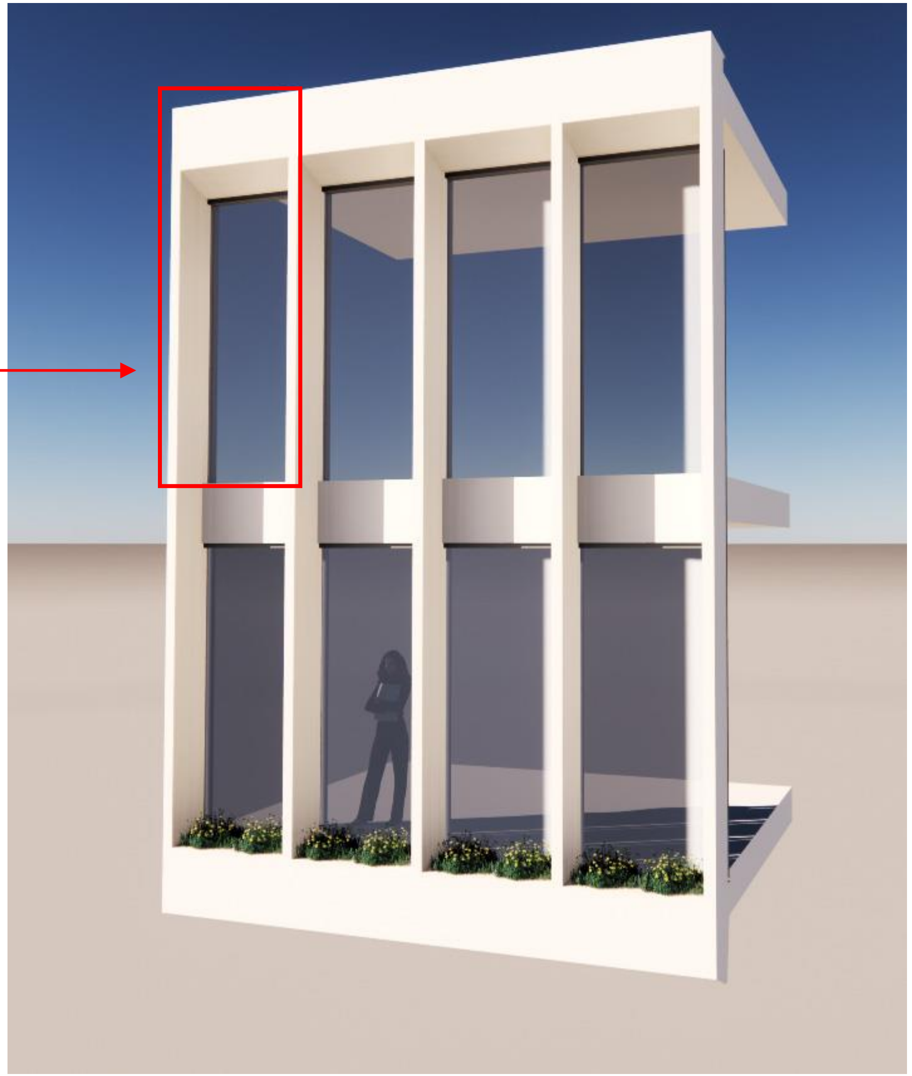
# Architectural Proposal, Aluminum

# Architectural Proposal, Aluminum Façade fragment

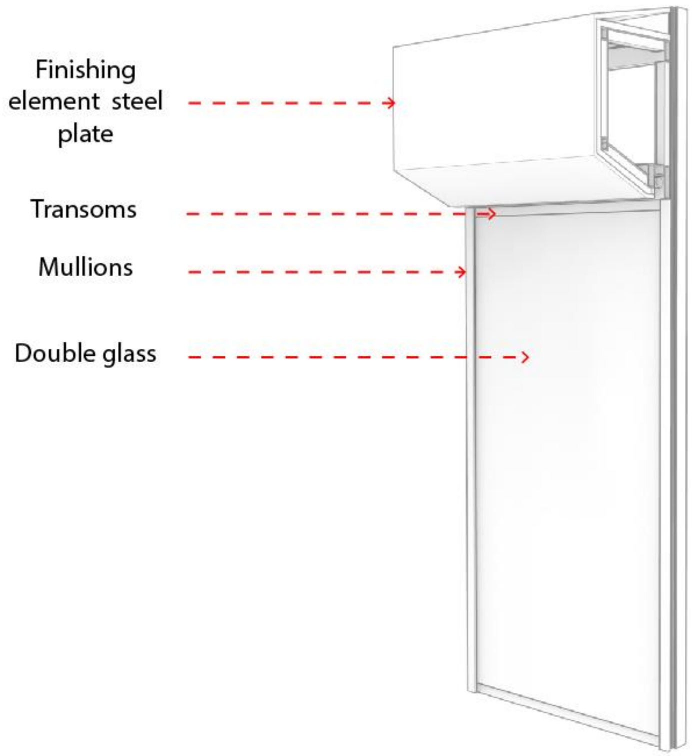


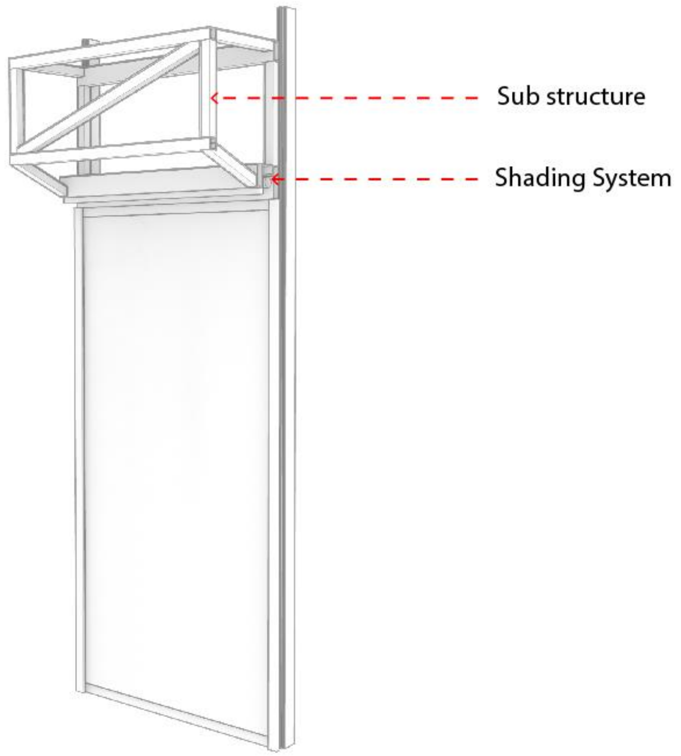



## Fragment units



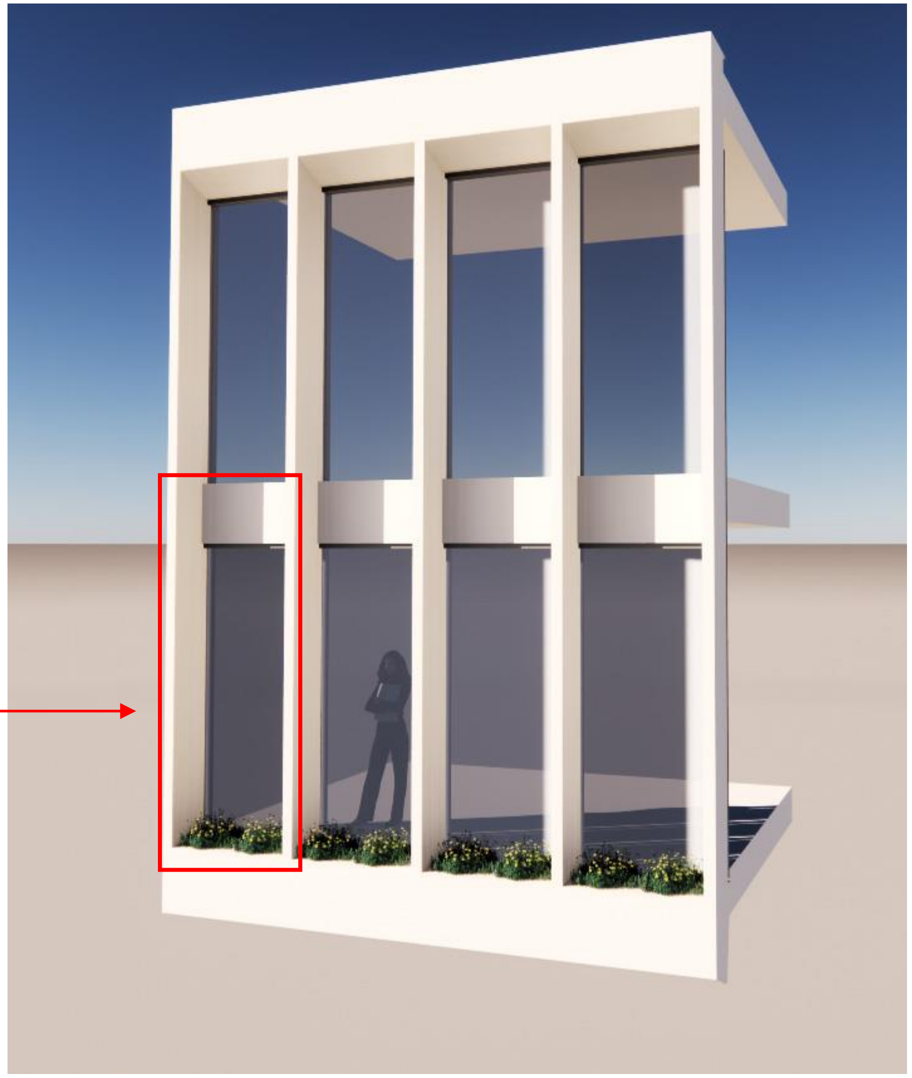
## Fragment units



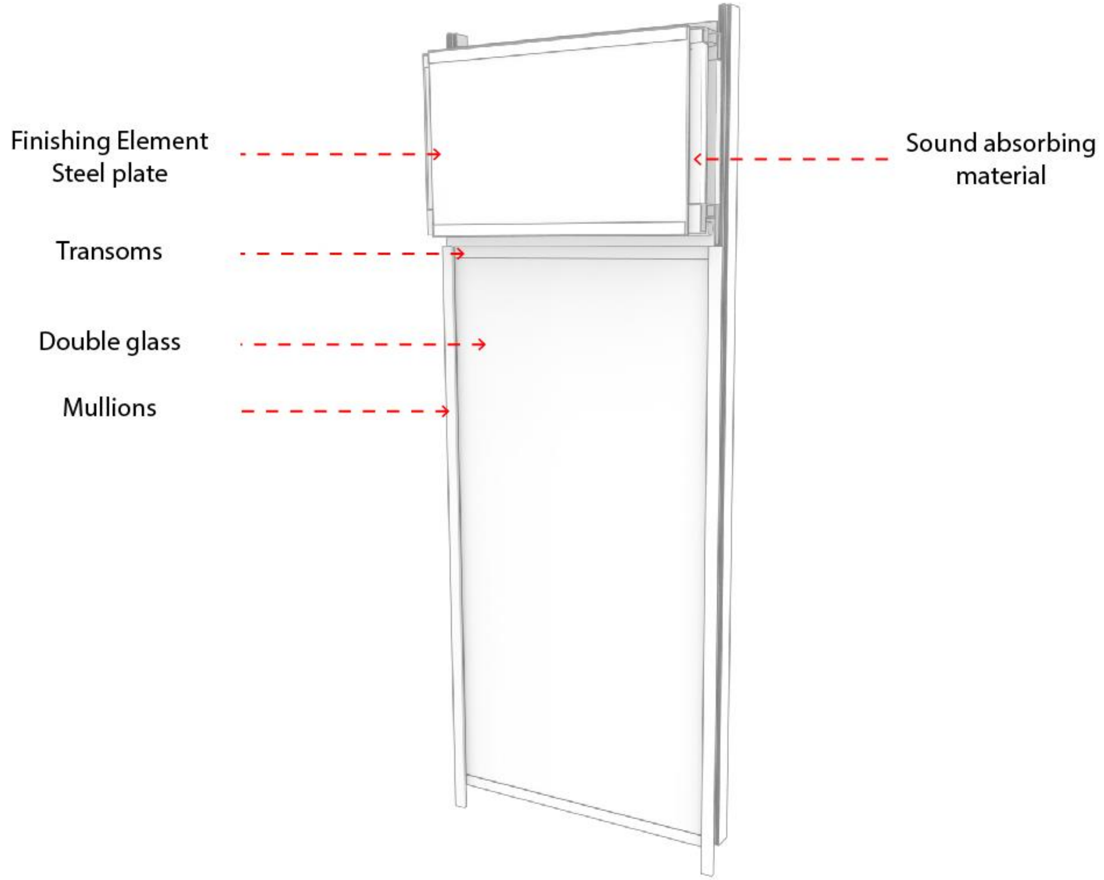



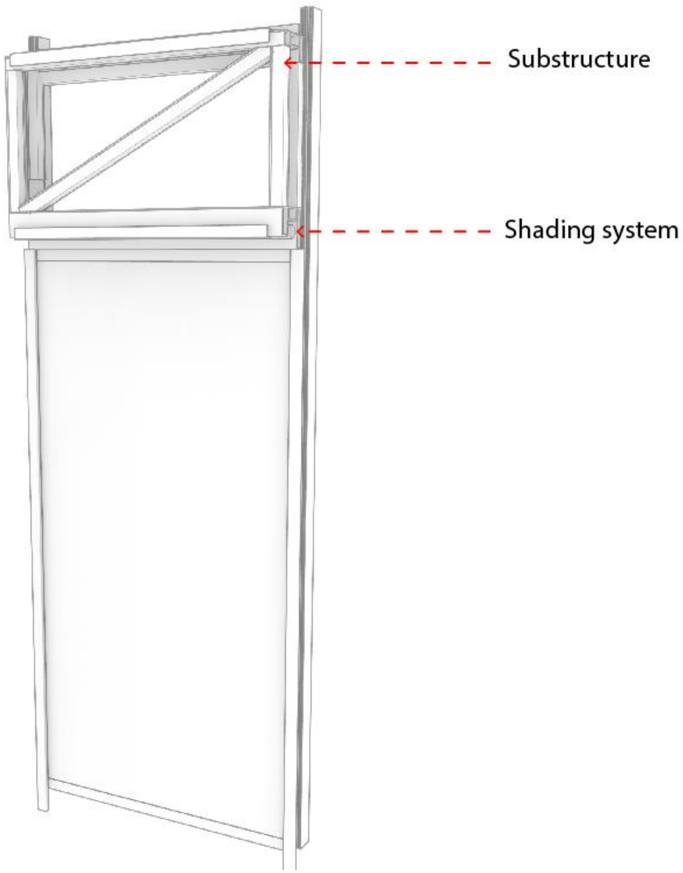

Mass: 317.9 Kg
Weight: 3118.59N
Frequency: 0.1sec
Stiffness Ky:1773366.17 N/m
Beam Length=1.35m

## Fragment units



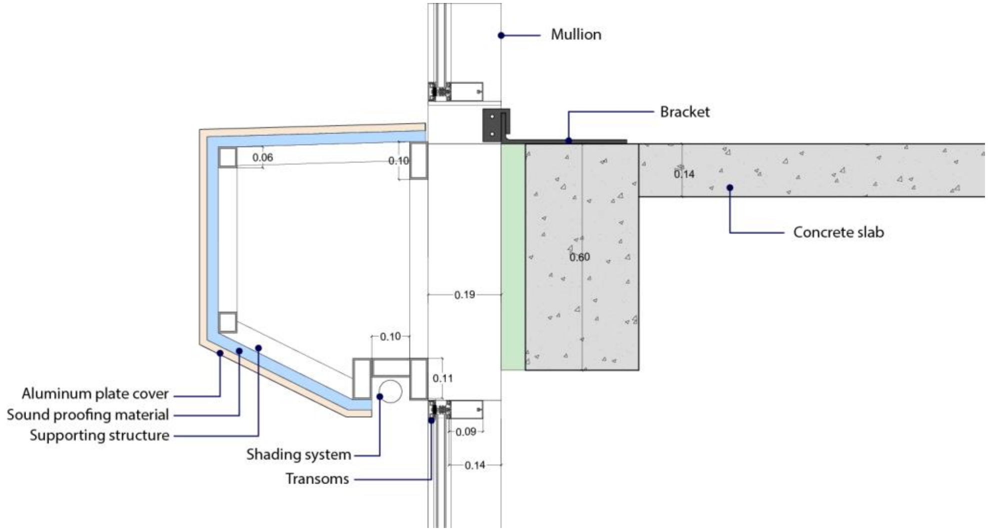
# Fragment units

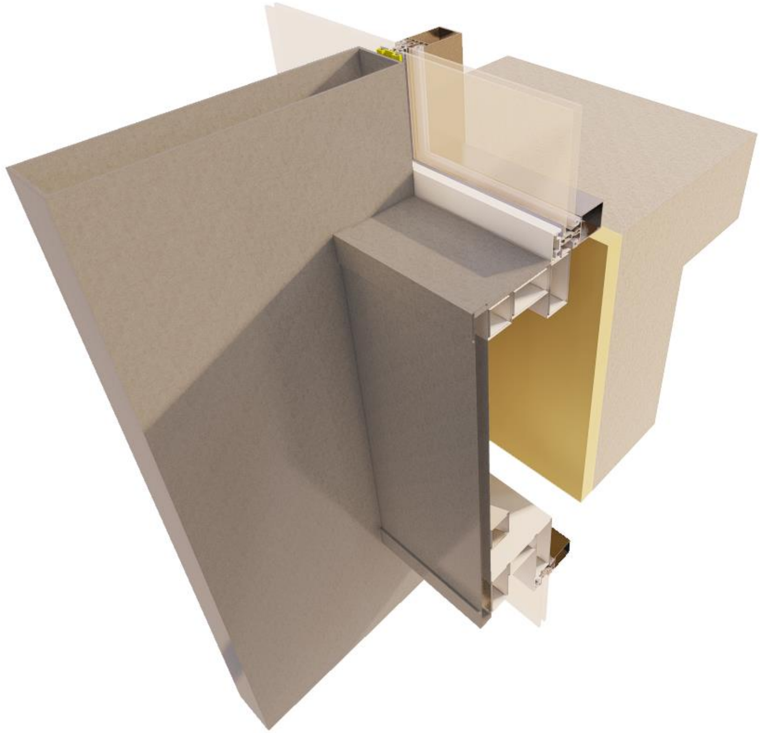



Mass: 306,8 Kg
Weight: 3025N
Frequency: 0.09sec
Stiffness Ky:1773366.17 N/m
Beam Length=1.35m

# Fragment Detailing Aluminum Facade

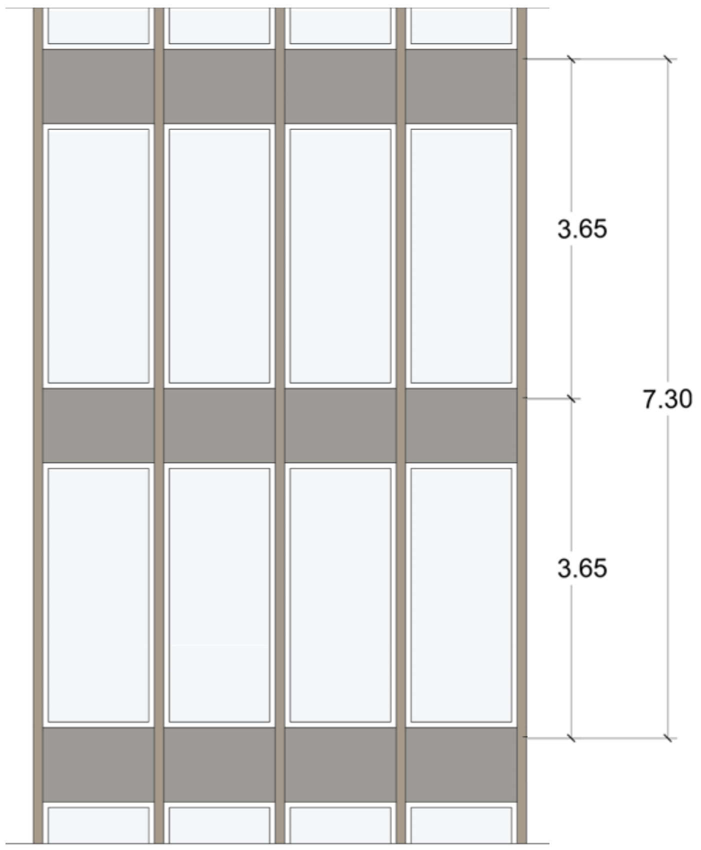


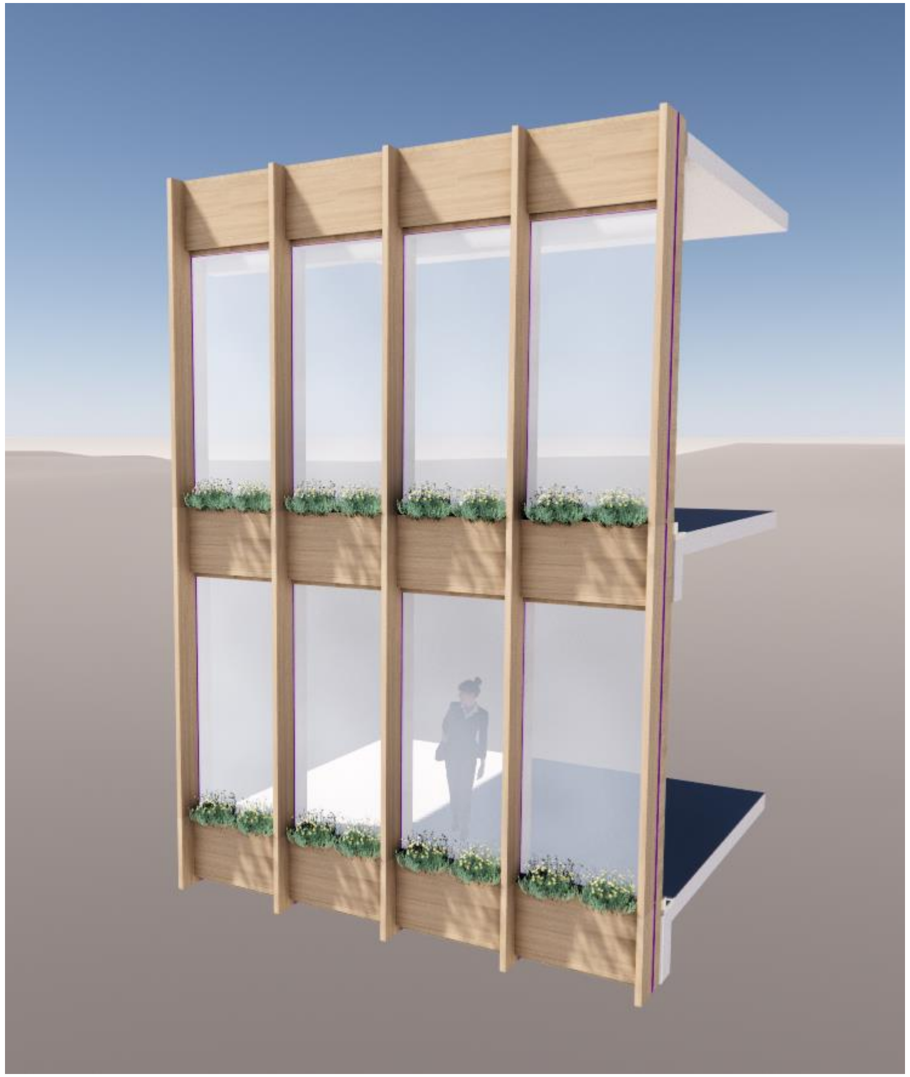



# Architectural Proposal, Wood Composite facade

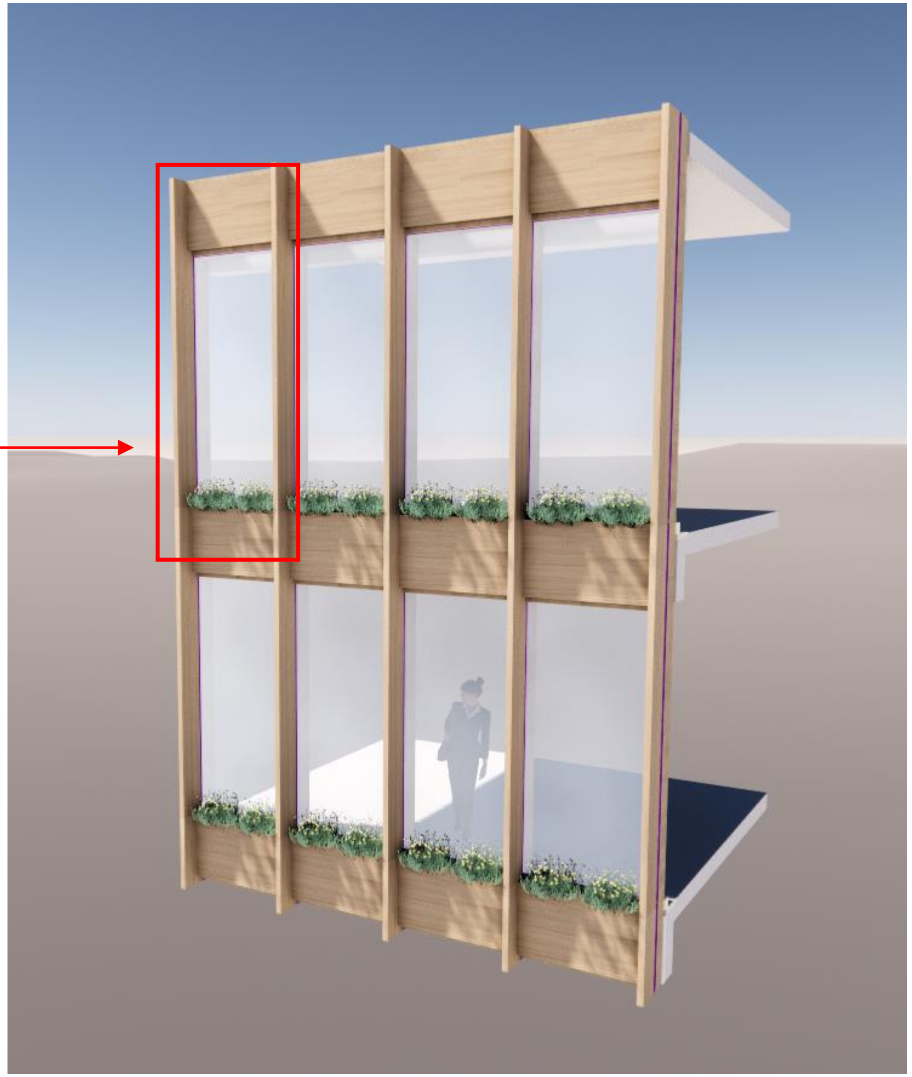
# Architectural Proposal, Timber

# Architectural Proposal, Timber composite Façade fragment

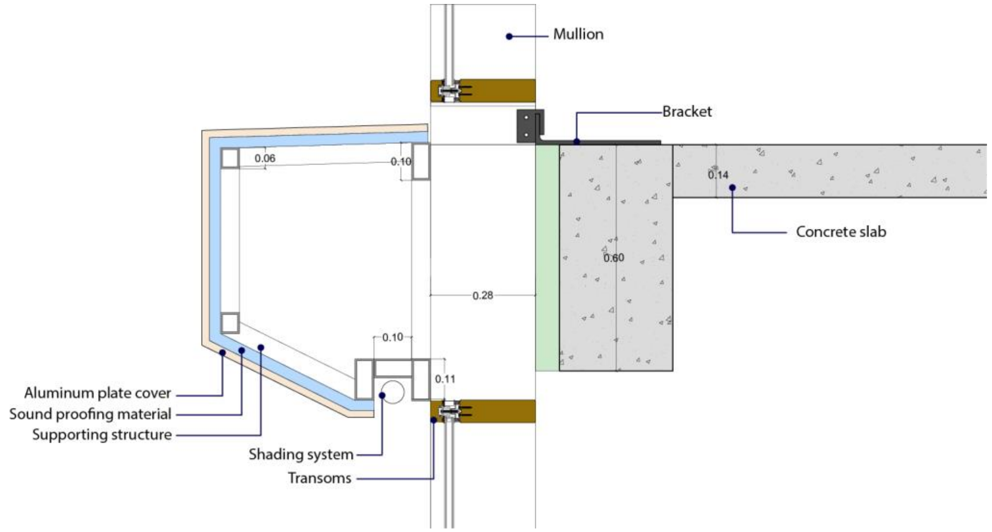


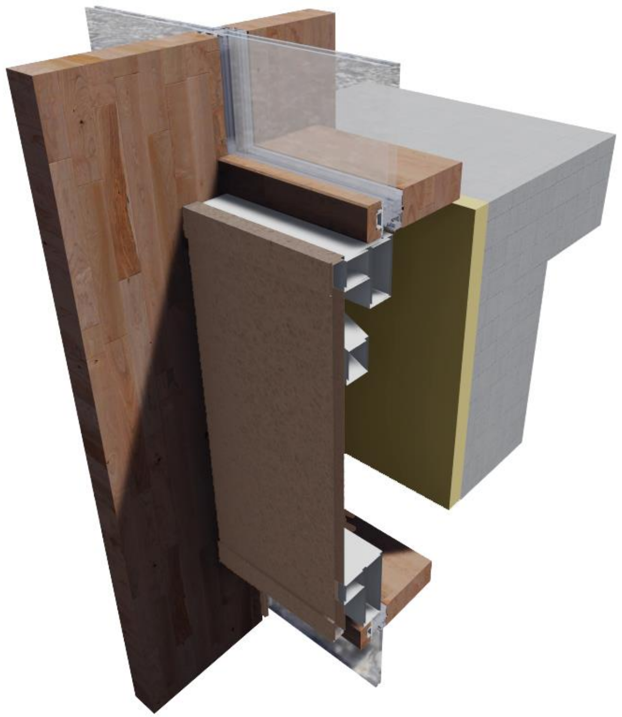



# Fragment units

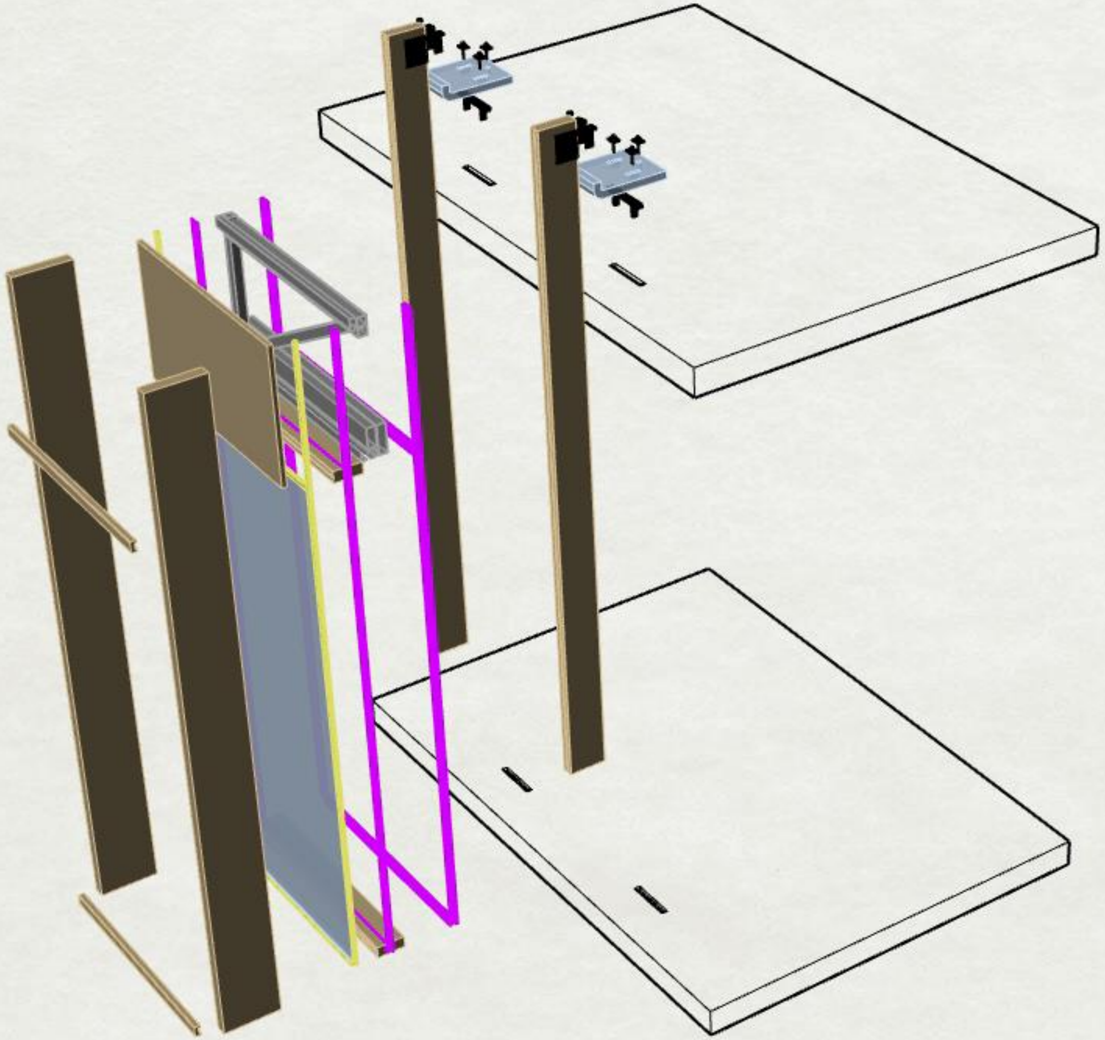


# Fragment Detailing Wooden Facade



# Fragment Detailing Wooden Facade



# Suspended facades Structural Analysis, Freeform Diagram

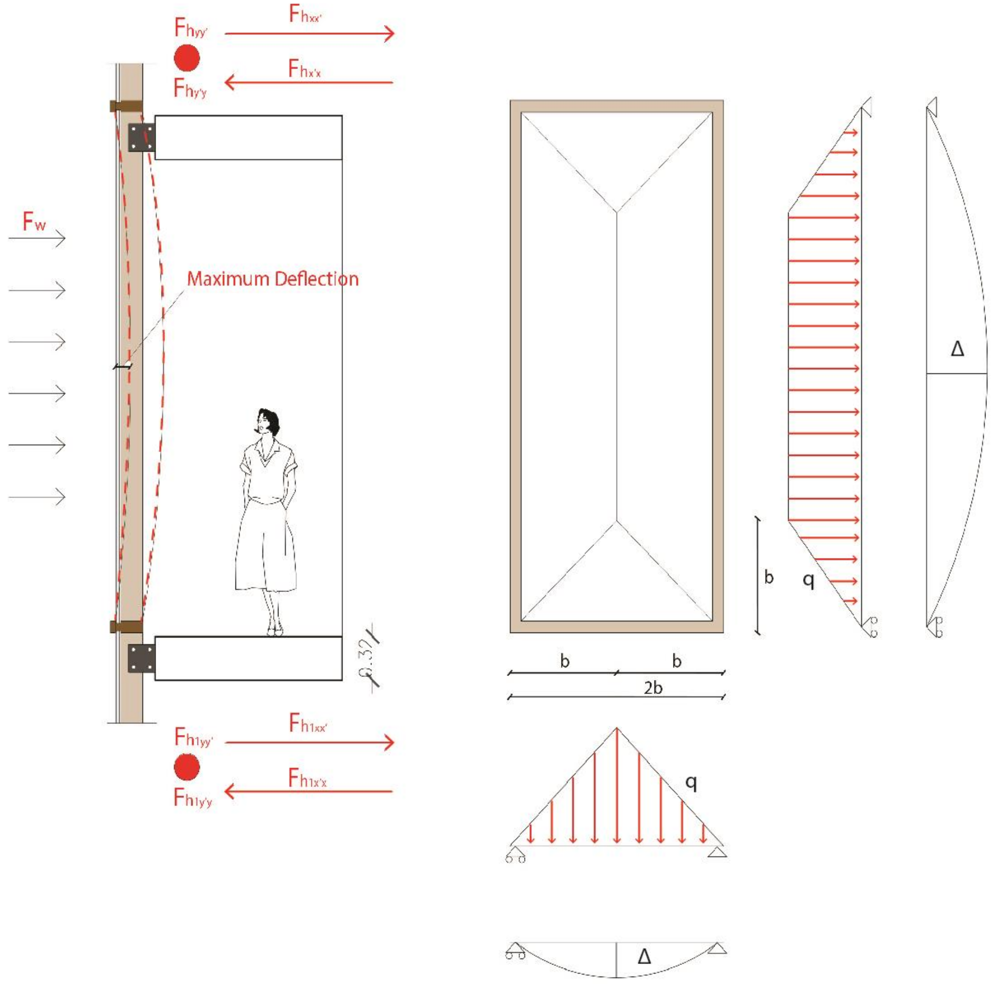
$$F_a = \frac{S_a * W_a * \gamma_\alpha}{q_a}$$

| | |
|---|---|
| Fa | horizontal seismic force, acting at the centre of mass of the non-structural element in the most unfavourable direction; |
| Wa | weight of the element |
| Sa | is the seismic coefficient applicable to non-structural elements, (see (3) of this subclause) |
| γa | is the importance factor of the element |
| qa | is the behaviour factor of the element |

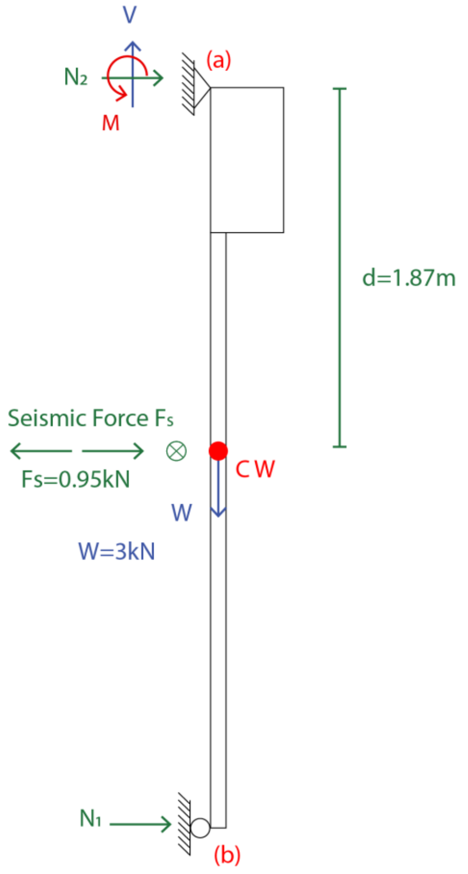
**$S_a$ Seismic coefficient applicable to non-structural elements**

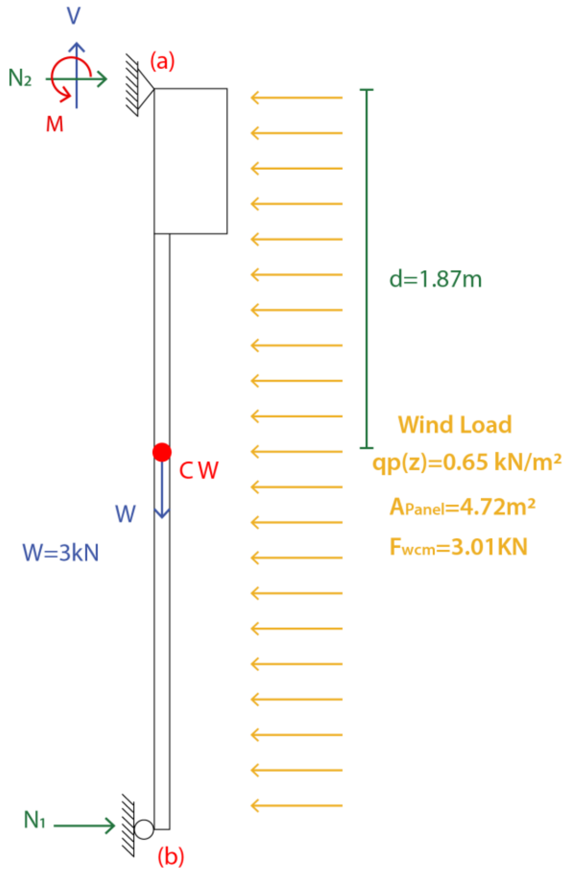
$$S_a = a * S * \left[ \frac{3 * \left(1 + \frac{z}{H}\right)}{1 + \left(1 - \frac{T_a}{T_1}\right)^2} - 0.5 \right]$$

| | |
|---|---|
| a | is the ratio of the design ground acceleration on type A ground, ag, to the acceleration of gravity g |
| S | is the soil factor |
| Ta | is the fundamental vibration period of the non-structural element |
| T1 | is the fundamental vibration period of the building in the relevant direction |
| z | is the height of the non-structural element above the level of application of the seismic action (foundation or top of a rigid basement) |
| H | is the building height measured from the foundation or from the top of a rigid basement. |



## Suspended facades Structural Analysis, Freeform Diagram



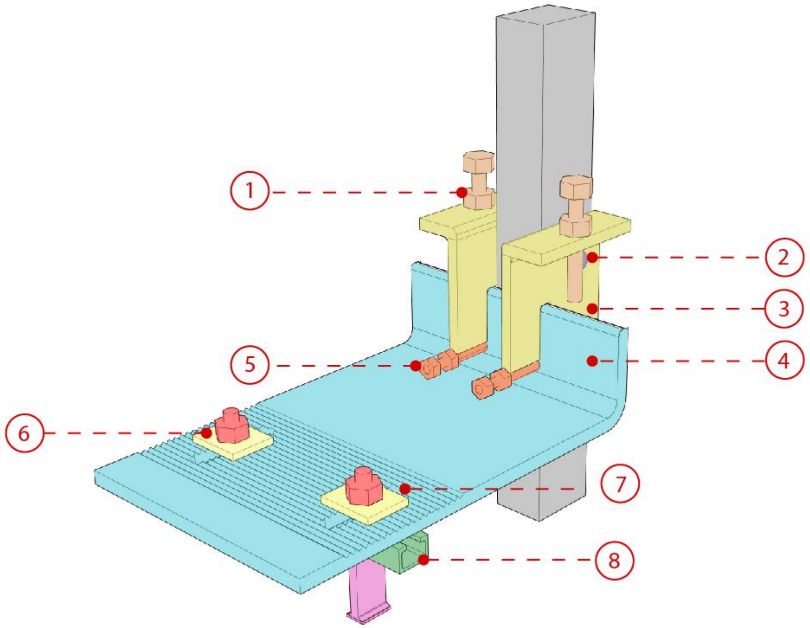
## Suspended facades Structural Analysis forces Combinations

| Forces applied | Perpedicular(yy') | Horizontal(xx') | Vertical(zz') | Momentum |
|---|---|---|---|---|
| **Weight** | | | 3000N | |
| **Wind first floor 0.65 kN/m²** | | 3000N | | 700N/m |
| **Seismic Forces first floor** | 950N | 950N | | 30N/m |

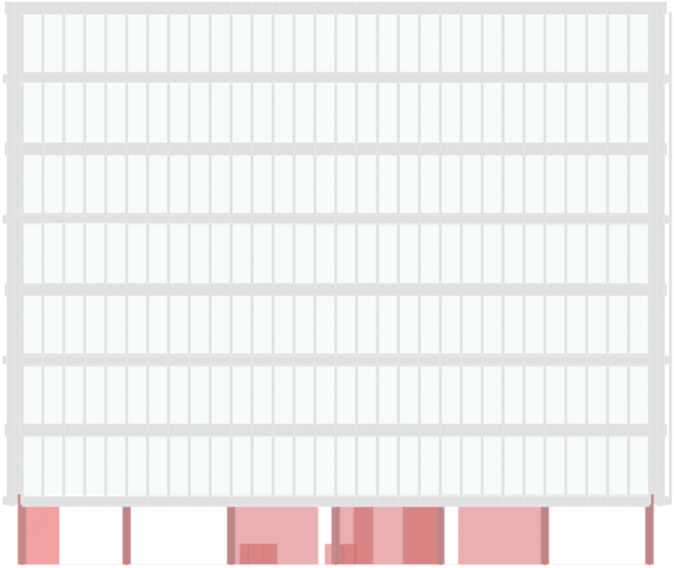
| Forces Combinations | Perpedicular(yy') | Horizontal(xx')(N) | Vertical(zz')(N) | Momentum(N/mm) |
|---|---|---|---|---|
| **Weight+Wind** | | 3000 | 3000N | 700N/m |
| **Weight+Seismic Force xx'** | | 950 | 3000N | 30N/m |

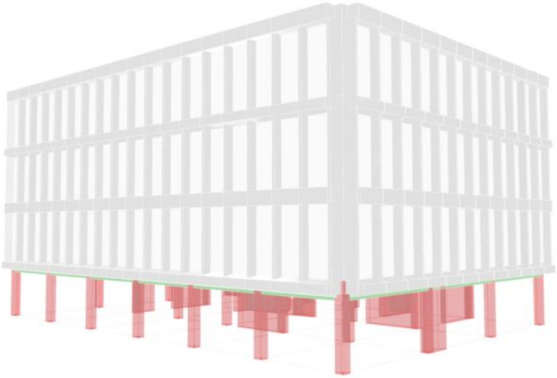
# Suspended facades Structural Analysis, Bracket Design, node diagram

1. Vertical Adjustments
2. Structural Node a fixed support
3. Structural Node b sliding support
4. Steel plate
5. Horizontal Adjustments
6. Structural node c sliding support
7. Structural node d sliding support
8. Channel taking horizontal loads

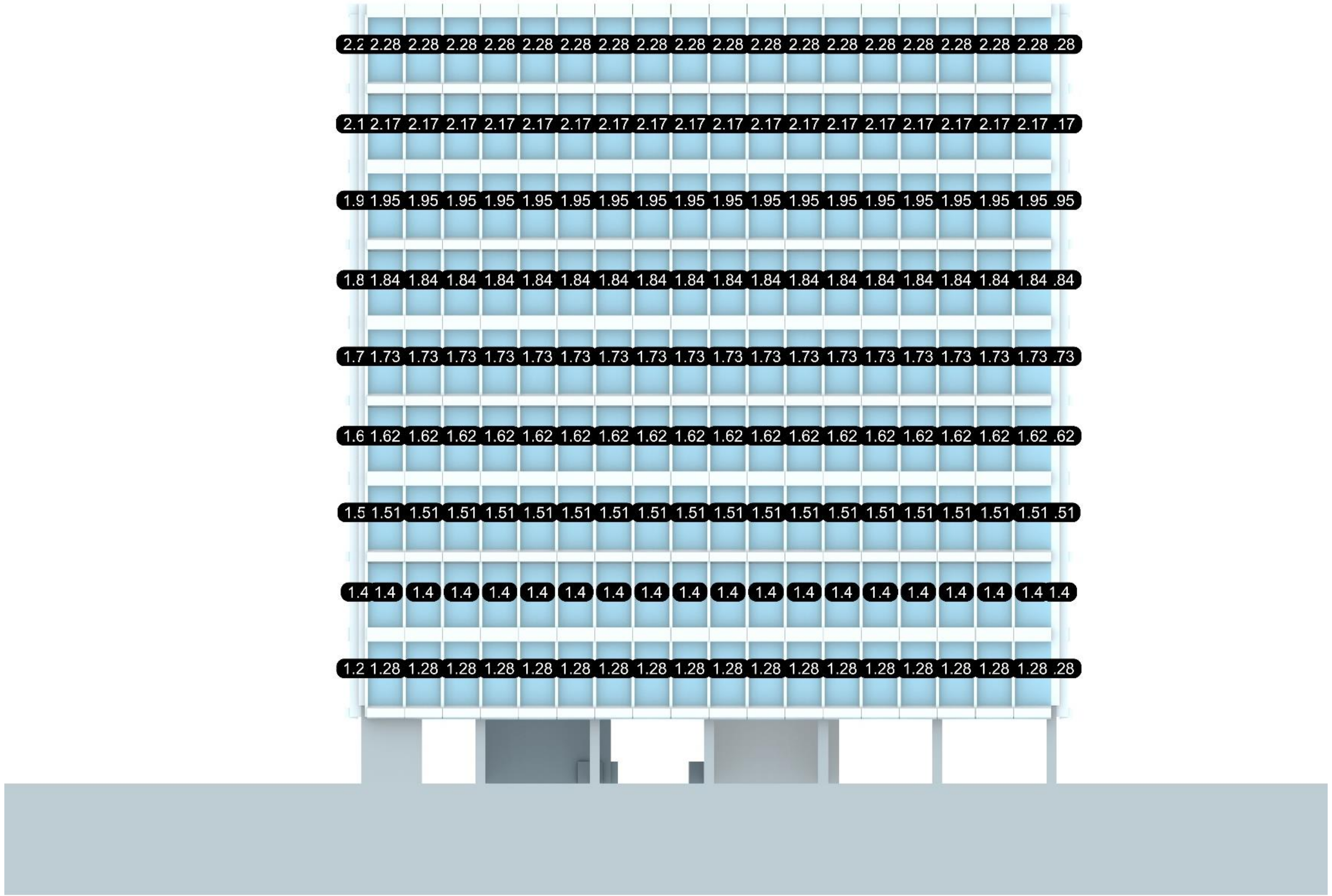


## Computational tool

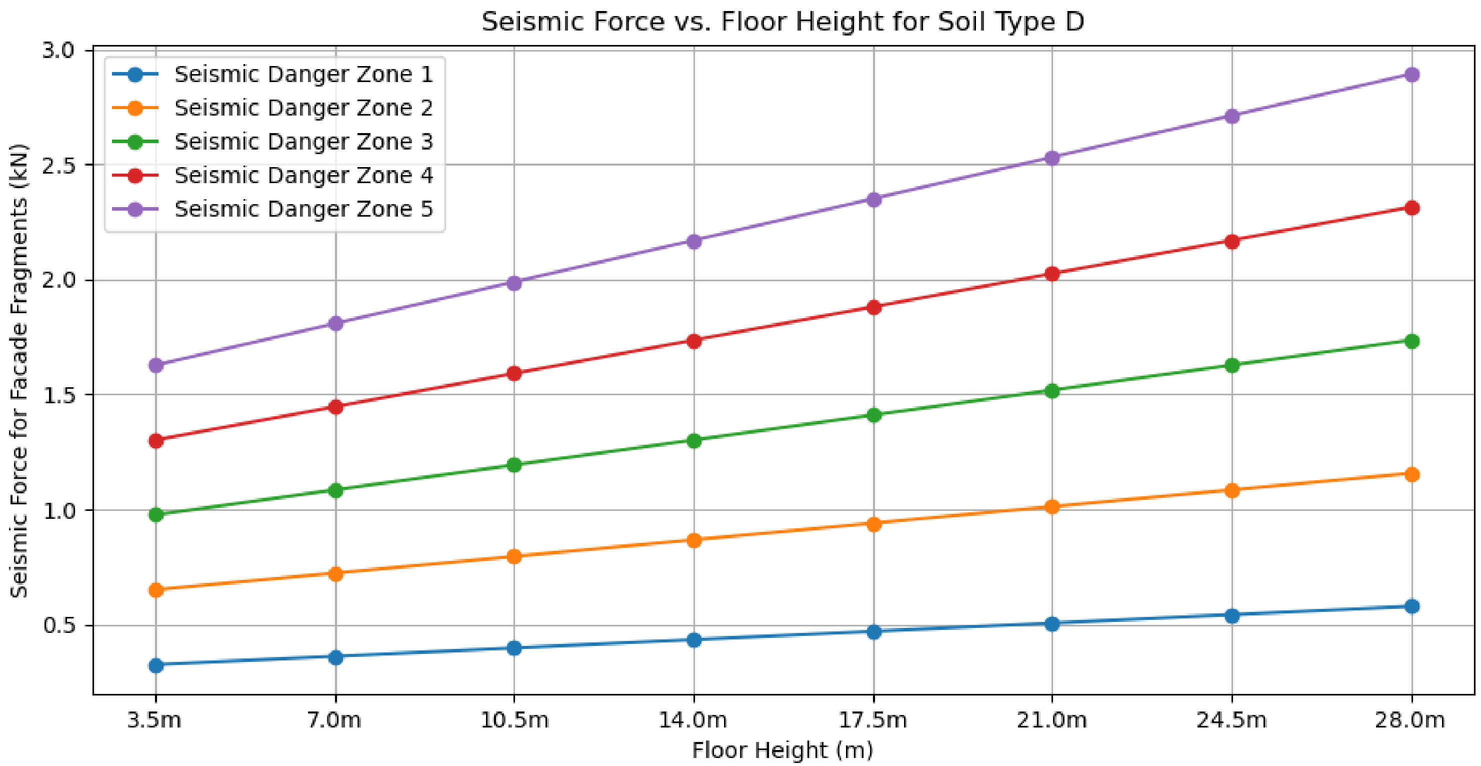




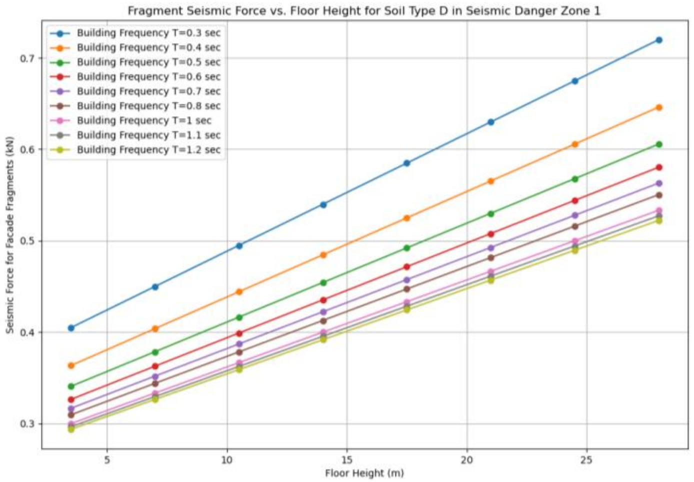
# Computational tool

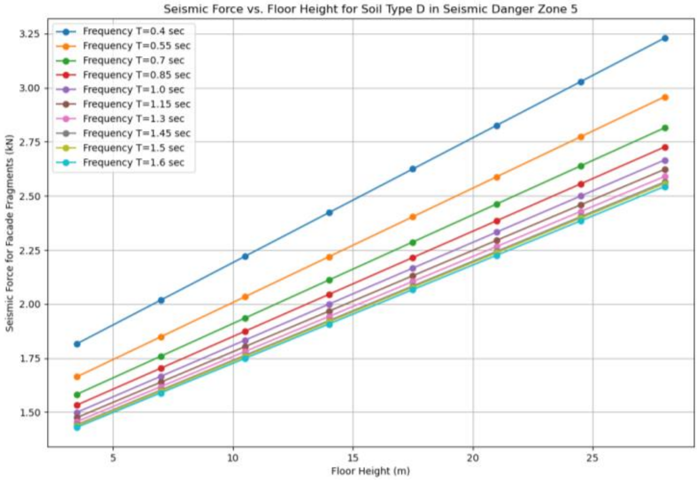


# Data analysis, Seismic force according to the Building height



# Data analysis, Seismic force with different building frequencies




General Observations:

- Seismic forces consistently increase with the buiding height and decrease with the building frequency across all seismic danger zones.
- The rate of increase in seismic forces is higher in zones with greater seismic danger.

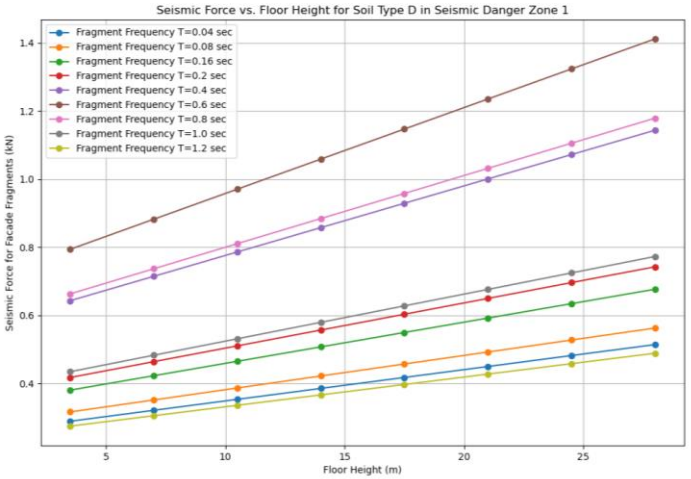
Design Implications:

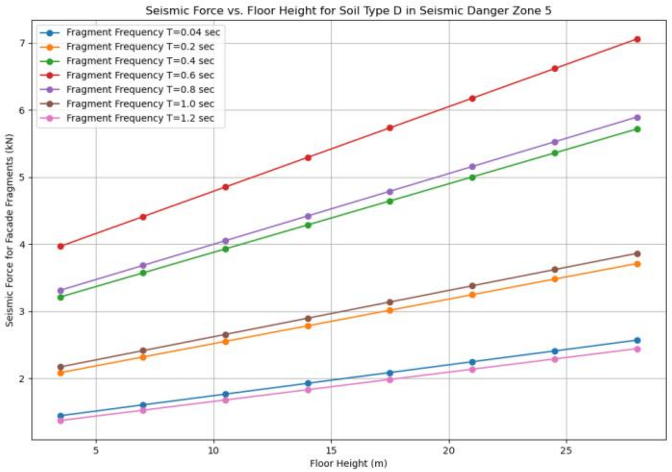
- Low-Frequency Buildings: Need robust seismic design to handle higher forces.
- High-Risk Zones: Advanced engineering solutions and materials are essential.
- Predictive Modelling: Reliable linear trends allow for effective use of height and frequency in predicting seismic forces.

$$F_a = \frac{S_a * W_a * \gamma_\alpha}{q_a}$$

$$S_a = a * S * \left[ \frac{3 * \left(1 + \frac{Z}{H}\right)}{1 + \left(1 - \frac{T_a}{T_1}\right)^2} - 0.5 \right]$$

# Data analysis, Seismic force with different facade Frequencies




Façade fragment frequencies range from T=0.04 seconds to T=1.2 seconds.

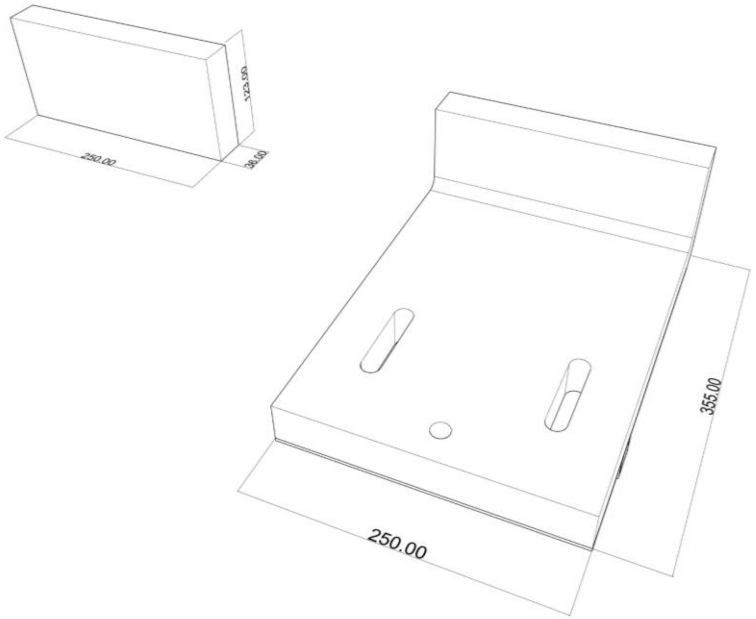
General Observations:

- The seismic force exhibits a linear increase with floor height. This trend is consistent across all fragment frequencies.
- When the fragment frequency matches the building's frequency the resonance effect takes place resulting the highest seismic force the fragments must withstand(the decrease of the force can reach 200%). The grater the difference from the resonance frequency the smaller the seismic force a fragment must withstand.

Design Implications:

Engineers should focus on broadening the difference between the building’s natural period compared to the facades frequency to avoid resonance with predominant seismic frequencies. This can be achieved through structural stiffening and optimizing the distribution of mass of the fragment. In parallel materials with higher damping properties should be considered to dissipate seismic energy effectively.

# Development of a structural Glass Bracket Connection




**A 350mm long glass bracket with a height of 120mm is supporting a design axial action of 2.51kN**

| | | |
|---|---|---|
| Lcr | 120 | wall height |
| b | 350 | length |
| t | 12 | thickness |
| N | 2.51 | kN |

**Pernament load action>50 years**

| | |
|---|---|
| kmod | 0.29 |
| $k_{sp}$ | 1 |
| $f_{gk}$ | 45 |
| $f_{bk}$ | 120 |
| $k_v$ | 1 |
| $\gamma_{MA}$ | 1.6 |
| $\gamma_{Mv}$ | 1.2 |

| | | | |
|---|---|---|---|
| fgd | 70.7 | N/mm2 | fgd = (kmod ·ksp ·fgk / γMA)+(kv ·(fbk-fgk)/γMv |

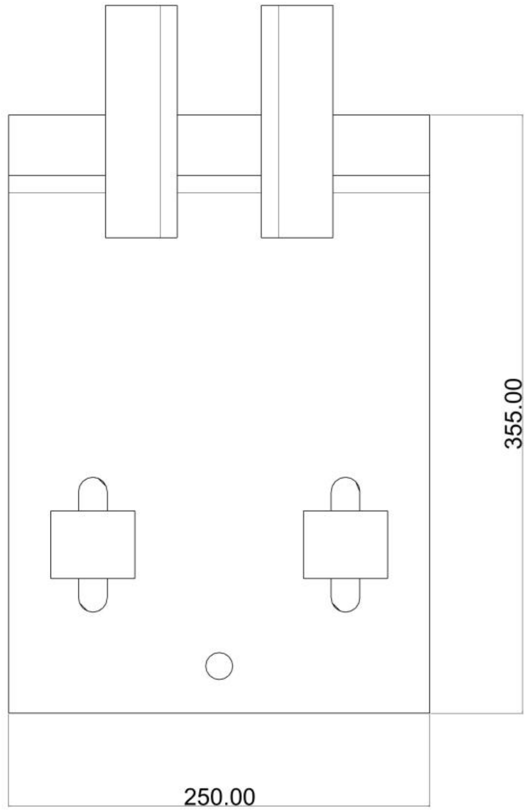
**Due to reduntacy requirement and the nature of the acion beeing pernament, the lamination cannot me considered to be composite and only one of the 12mm thick piles can be regarded tobe acting as a supporting element.**

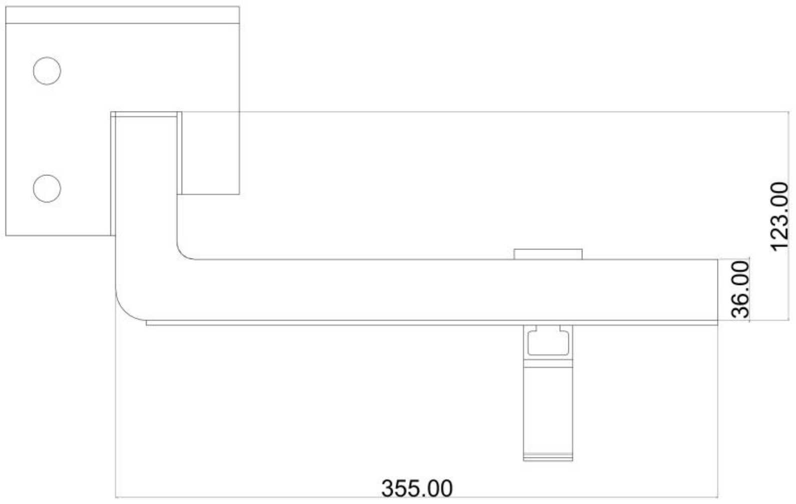
| | | | |
|---|---|---|---|
| $N_{cr}$ | 828206 | N | Ncr = ( $\pi^2$ ·E·I)/($Lcr^2$ ) |
| | 828.2 | kN | |
| Emod | 70000 | N/mm2 | |
| I | (b*h^3)/12 | | 17280 |
| W | 8400 | mm3 | W = $b \cdot t^2 /6$ |
| w0 | 0.40 | mm | Wo = L/300 |
| Wmax | 0.40 | mm | Wmax = wo/(1-((N*10^3)/(Ncr*10^3))) |
| $\sigma_{max}$ | 0.72 | N/mm2 | σmax = (N*10^3)/(b*t)+((N*10^3)/W)*Wmax |

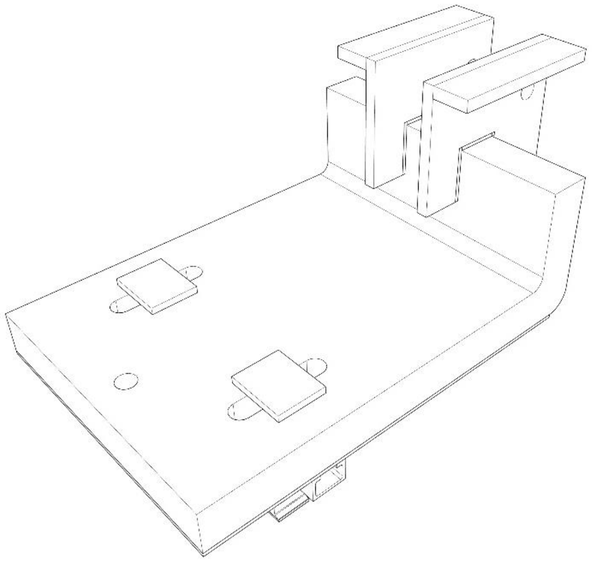
Checking the combination between axial force and bending moment the following expression applies:

| | | | |
|---|---|---|---|
| E | 0.01 | OK | E=N/Ncr + σmax/fgd <1 |

# Development of a structural Glass Bracket Connection

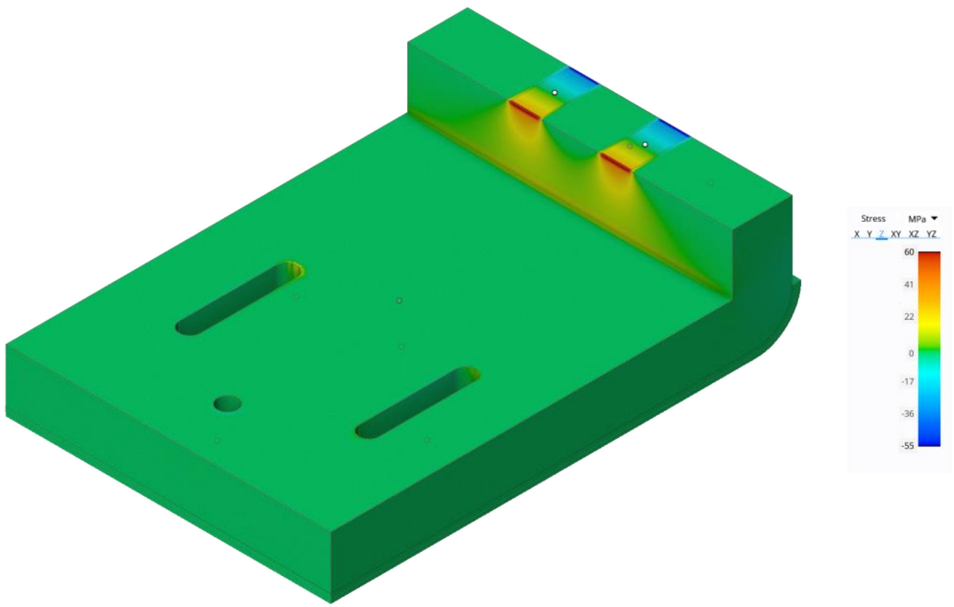


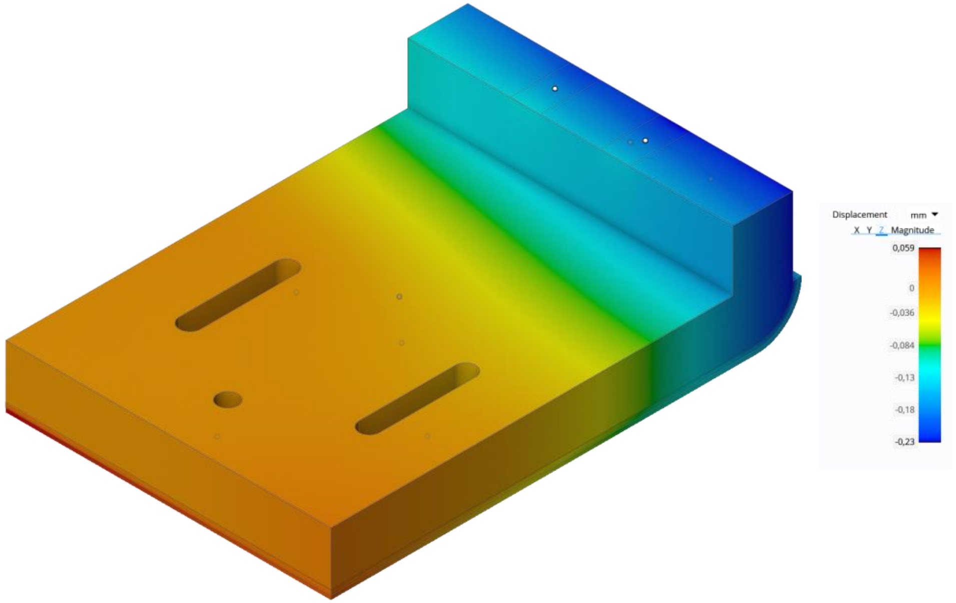



# Development of a structural Glass Bracket Connection

## Weight, Wind force Applied



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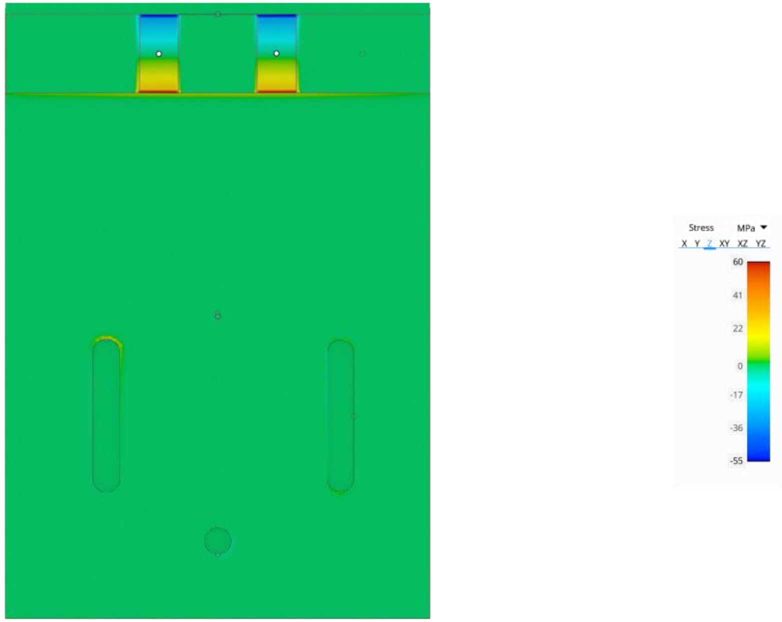


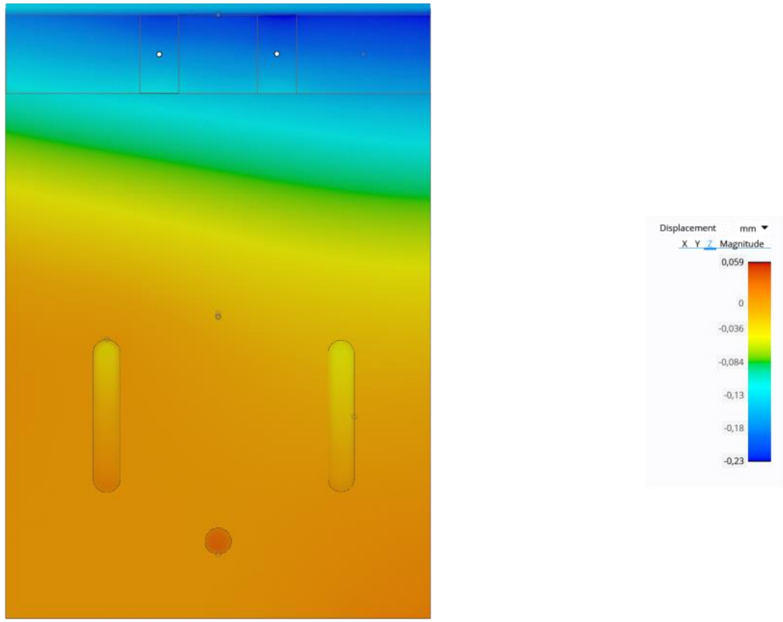

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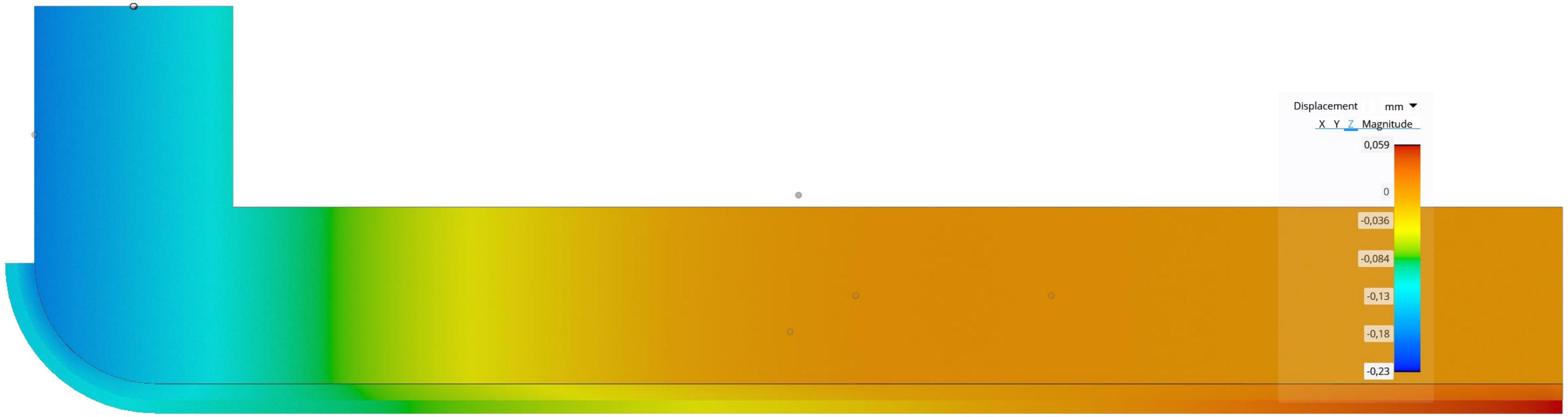
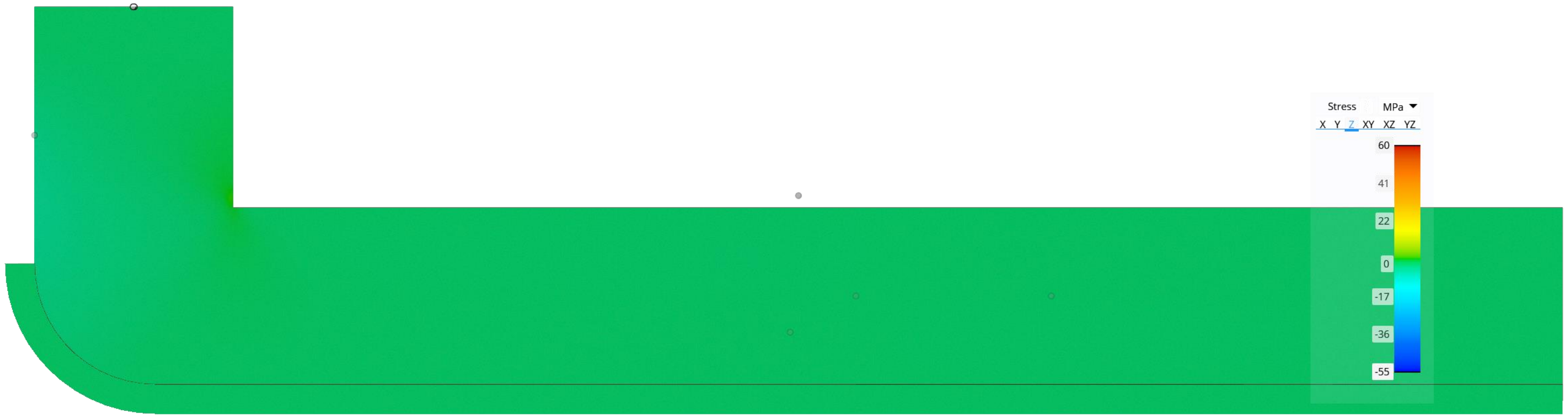
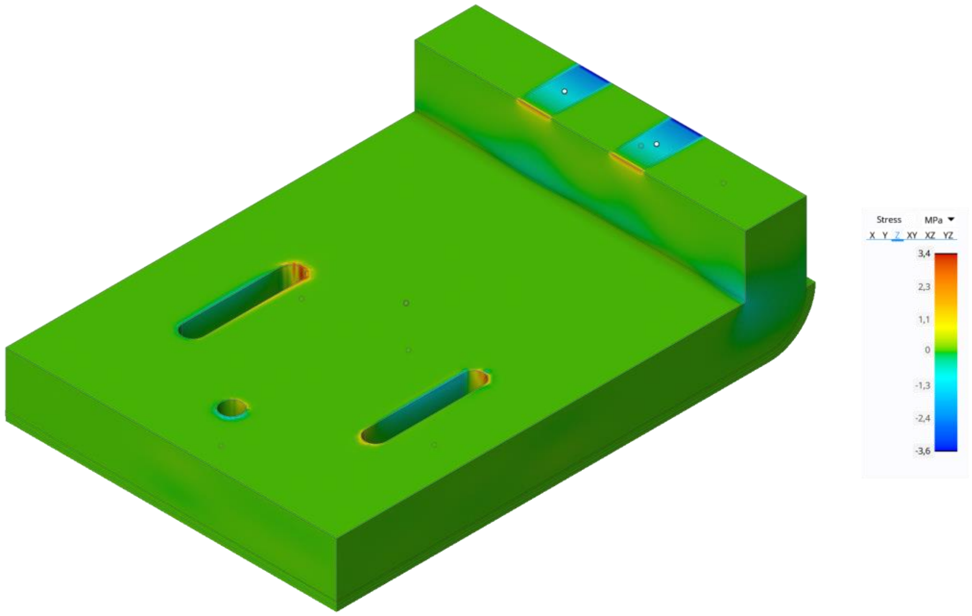
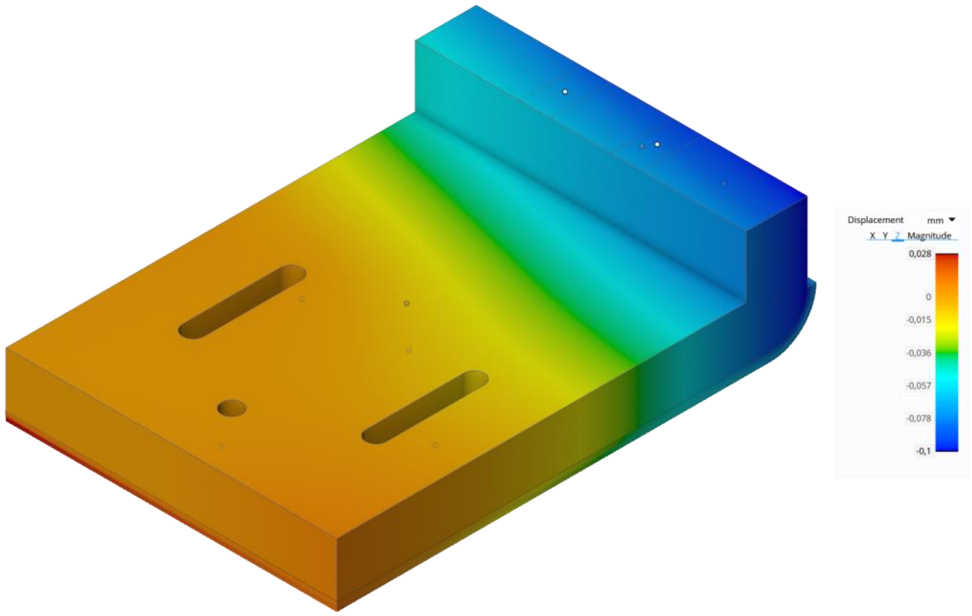


# Development of a structural Glass Bracket Connection

## Weight, Seismic Force Applied



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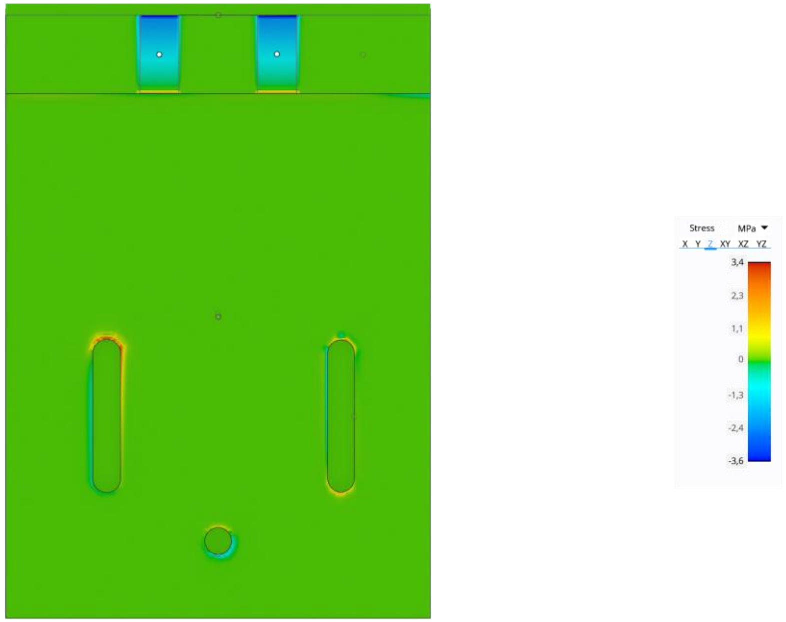
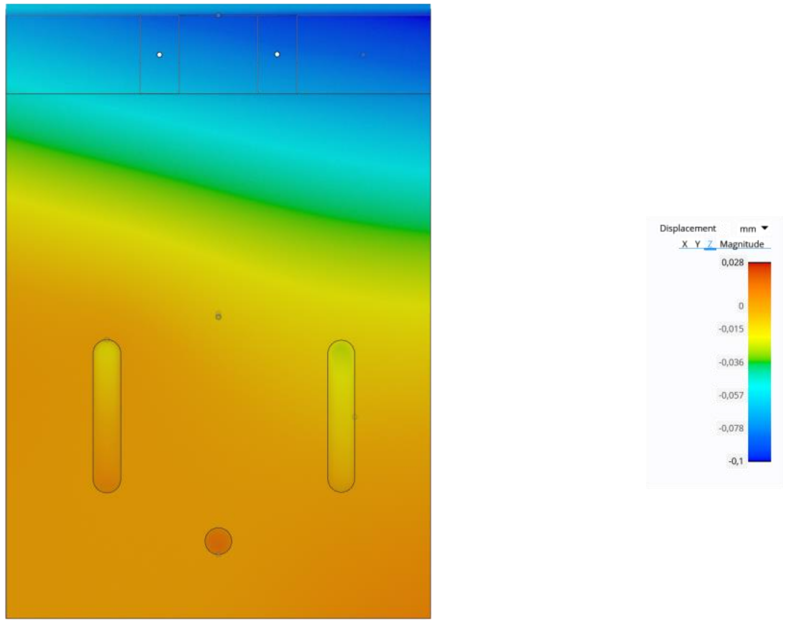
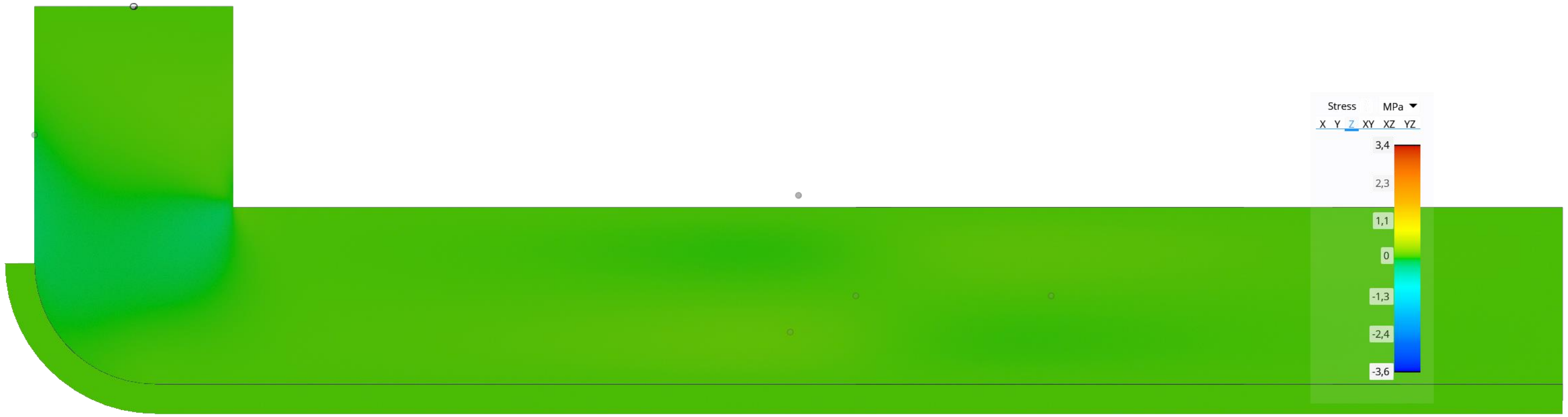
## Weight, Seismic Force Applied

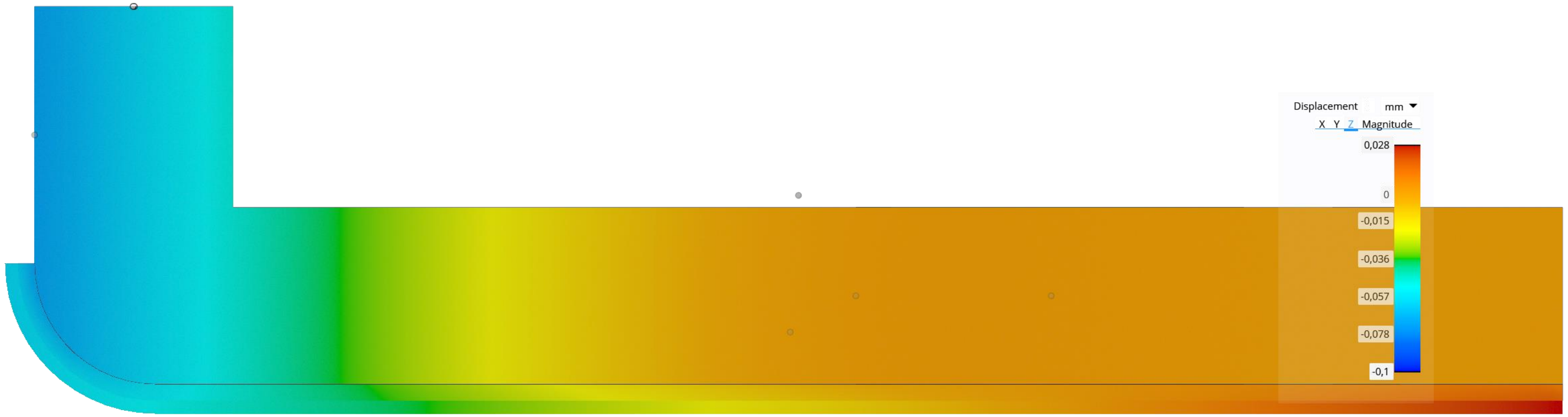


# Development of a structural Glass Bracket Connection

## Weight, Seismic Force Applied

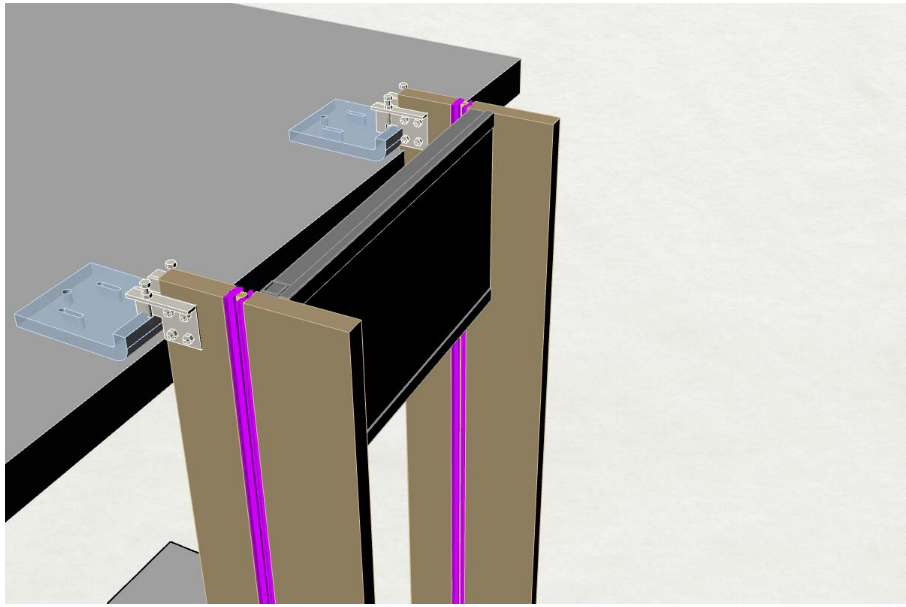


# Conclusions

**How brackets withstand extreme conditions such as earthquakes?**

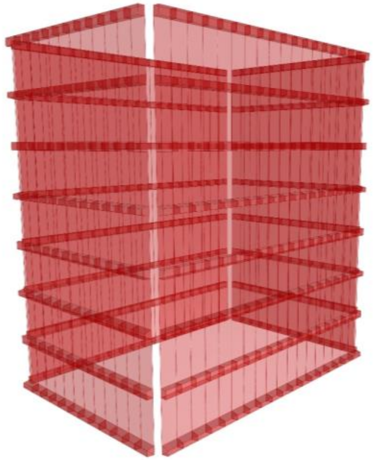
- During extreme wind loads and earthquakes, multi-directional movements must be considered.
- The anchorage system needs to be robust yet flexible to handle these movements without failure.
- Channels within the system withstand longitudinal forces, while brackets resist perpendicular forces.



# Conclusions

**How can a computational tool calculate the forces a suspended façade has to withstand from earthquakes and wind pressure?**

- Computational tools are essential for calculating forces on façades, attributed to earthquakes and wind pressure in complex modern architectural designs.
- Python and Grasshopper are tools that combine 3D façade generation with automated calculations, outputting seismic forces per façade fragment.



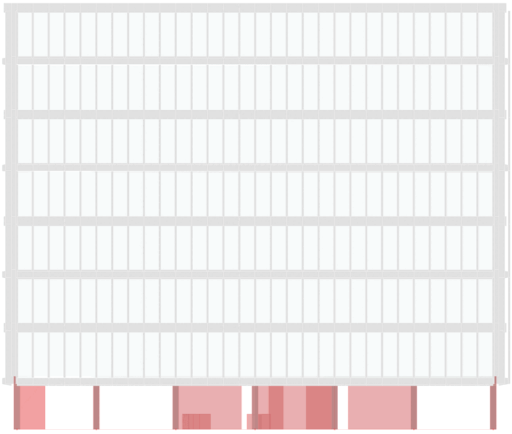
+

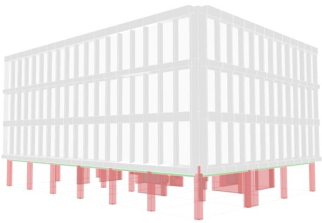
```
mf1kn = 0
mf1kn = mfa1* 9.81
LIFF1=[]
a1=0
Zh=[]
ZH=hght

while a1 < floors :
    a1 = a1 + 1
    Saf = a * S * ((3 * (1 + (ZH / H))) / (1 + (1 - (Tafr / T)) ** 2 - 0.5))
    FF1 = Saf * mf1kn*0.001 * gaf / qaf
# from N to KN
    FF1_rounded = round(FF1, 2)
    ZH = ZH + hght
    LIFF1.append(FF1_rounded)
    Zh.append(ZH)


print('the seismic force per panel per floor is',LIFF1)
```

## Conclusions

**How can the structural analysis of a façade become less challenging for architects, civil engineers', façade advisors?**

- Advancements in high-level and visual programming tools like Python and Grasshopper can streamlined the structural analysis of building façades.
- These tools facilitate the extraction and manipulation of data, enabling efficient calculations that combine the dimensions and placement of a façade fragment.
- Visual programming allows architects to optimize façade designs for both structural efficiency and aesthetic outcomes, enhancing collaboration among professionals.
- Leveraging advanced software makes structural analysis less challenging, resulting in designs that are both aesthetically pleasing, structurally sound and sustainable.

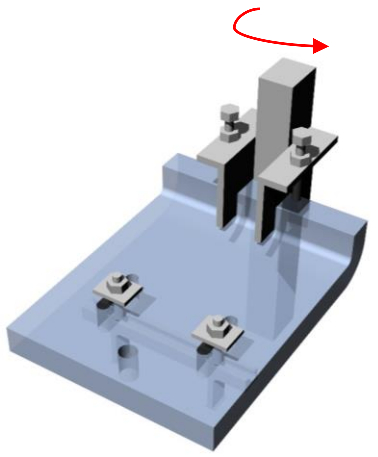




## Conclusions

**Can we use structural glass as a bracket system and withstand seismic wind forces?**

- Structural glass in bracket systems presents challenges due to its brittle nature and lack of ductility, making failure difficult to predict and manage.
- Proper design considerations much like incorporating in-between elastomer materials, can help withstand torsional movements during earthquakes and can help structural glass withstand seismic forces.
- Comprehensive load analysis and rigorous safety measures can make structural glass a viable option for bracket systems in seismic and wind-prone areas.
- The internalized carbon of this bracket system needs to be addressed.

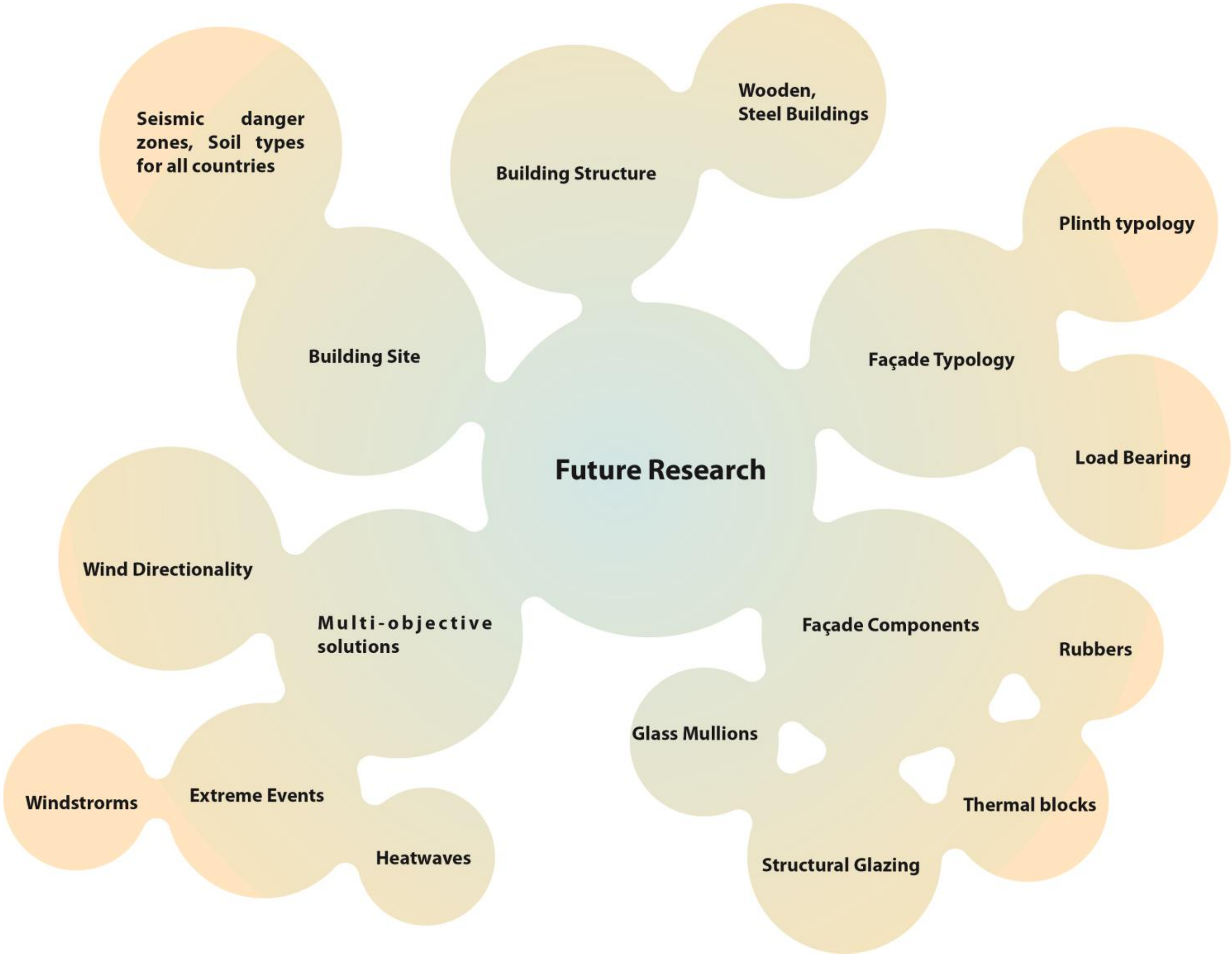


# Conclusions

**How can the efficiency of researching new materials for a façade system in extreme conditions such as earthquakes be improved?**

- Utilizing advanced computational tools, such as high-level programming languages and visual programming tools, can streamline the analysis of new façade materials for extreme conditions.
- Implementing advanced simulation and modelling techniques can predict the behaviour of new materials under extreme conditions, optimizing designs before physical testing.
- Encouraging collaboration and data sharing among architects, engineers, material scientists, and industry experts can accelerate the development of innovative solutions.
- Integrating automated testing and prototyping can reduce time and human error, making the research process for new façade materials more efficient.

# Future development



**Thank you for your attention!**